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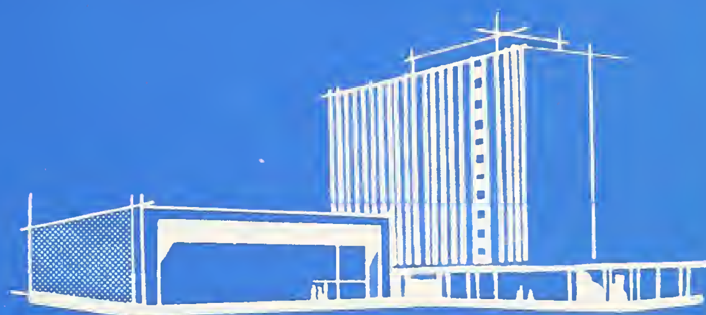

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# Precoordination—Basis for Industrialized Building

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151

# Precoordination—Basis for Industrialized Building

**Proceedings of a Conference**
**Held at Gaithersburg, Md.**
**September 24–26, 1969**

**Edited by**

**Russell W. Smith, Jr., Conference Chairman**

**Building Research Division**
**Institute for Applied Technology**
**National Bureau of Standards**
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## Abstract

The Conference entitled "Precoordination—Basis for Industrialized Building" was held at the National Bureau of Standards, Gaithersburg, Md., on September 24–26, 1969. The Conference was sponsored by the American National Standards Institute's Committee A62, Precoordination of Building Components and Systems, to explore the standards required to establish a basis for an industrywide system of building using interchangeable components. Coordinated components, conforming to these standards, will be compatible and interchangeable in both dimension and function and thereby offer unlimited opportunities for product and material selection as well as design flexibility.

Key words: Building; components; precoordination; standards.

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## Foreword

Inadequate numbers of adequate housing units is one of the major problems facing our Nation today. Many authorities on the building process believe our quantitative and qualitative objectives can be met through a kind of assembly-line approach in which modular components are dimensionally and functionally coordinated in advance of their arrival at the building site. To be operable and effective, this precoordination approach requires standards on which to base product design.

Recognizing the need for such standards, and that a broad-based effort was required in their development, NBS proposed in 1965 the formation of a committee within the American National Standards Institute to deal with the problem. In response, ANSI Committee A62 was organized in October 1966, with NBS acting as its sponsor, and providing the secretariat as well as technical and administrative support.

As part of its continuing involvement in this area, NBS was pleased to host the recent Conference on Precoordination—Basis for Industrialized Building, and is equally pleased to make these proceedings available.

Lewis M. Branscomb, Director

## Preface

These are the proceedings of the Conference on Precoordination—the Basis for Industrialized Building, held September 24–26, 1969, at the National Bureau of Standards, Gaithersburg, Md., under the auspices of the American National Standards Institute's Committee A62 which is sponsored by NBS. The theme was selected to emphasize the importance of developing standards to precoordinate building components and systems both functionally and dimensionally, in terms of national need.

Most of the speakers dealt with subject areas in which A62 is actively developing coordination guidelines through the procedures of the American National Standards Institute. These standard guidelines are directed toward a building technology in which buildings would be erected through the assembly of completely fabricated components with little or no modification required for final assembly. Both onsite and factory fabrication of components are envisioned.

The A62 effort is aimed at the precoordination of existing products and systems, converting these to components of an industrywide open system. Such components would be compatible and interchangeable in both dimension and function, thus maximizing the variety of materials and products from which selection can be made as well as maximizing the flexibility of design option.

Russell W. Smith, Jr.
*Secretary,* A62

# Contents

# Precoordination in a Modern Industrial Process

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There are many standardized components and practices utilized in the design and construction of a passenger car which make the product adaptable to mass production. Similar standardization must be applied to the design and construction of buildings if mass production is to be achieved in this industry, while at the same time maintaining flexibility to satisfy the variable conditions of nature and requirements of man.

Key words: Flexibility; mass production; standardized components and practices.

Nature's many products are formed under an orderly system of molecular structure and exist in natural environments. Human beings, in general, are all physically similar but are endowed with distinctly individual, unique characteristics and continue to strive for existence under ever-changing conditions.

Manmade products, as a prime objective, must be designed for compatibility with the variables of nature.

Automobiles are built to transport people, trucks are built to transport possessions of people; most buildings are constructed to house people, warehouses are constructed to house possessions of people. Since the beginning of time, man has directed his energies to caring for man.

In a sense, dynamic passenger cars and static structures for human occupancy are similar in that they must meet two basic requirements. First, environmentally, aesthetically, and functionally, they must be compatible with man's variable emotions and physical requirements. Second, these products must be compatible with and endure the variable atmospheric and ground conditions of nature.

These two products are dissimilar in that building structures, for the most part, are designed and built to remain in one geographic location, thereby enduring a limited range of variable atmospheric conditions. On the other hand, automobiles must operate throughout the world wherever suitable roads exist, performing over an extremely wide range of atmospheric conditions.

One major difference between a building structure and a passenger car is that an architect seeking optimum design with minimum cost must specify, where possible, existing materials and components that are available from suppliers, making compromises at interface positions to accomplish his overall design objectives. Many of these materials and components are catalog stock items, the specifications of which are established by many different technical and trade associations; therefore, the building structure usually results in a product which could not be initially engineered and pretested as a total entity, but consists of some components that must be modified onsite or at point of manufacture to accommodate conflicting interfaces in the construction. These modifications are usually time consuming and costly.

The passenger car, on the other hand, is for the most part a completely engineered entity with component interface compatibility which lends itself to mass production with lower costs and more dependable schedules. This results from completely coordinated control of engineering and production of all components and systems, pretested for performance and durability. Obviously, high sales volume of identical end product units is necessary to support organizations of the magnitude required to coordinate all aspects of engineering, production, local standards, and national standards that result in a high-quality product at minimum cost to meet marketplace requirements.

While central control and coordination is the key to mass production success, standards still play a vital part in the overall process.

Commercial and industrial standards are usually the results of agreement by authority, custom, or general consent to follow fixed specifications or methods in the design, manufacture, and sale of products. Such standards are usually established to solve recurring problems and, more specifically, to assure interchangeability, serviceability, or integrity.

Many standards are used in the automobile industry. As an example, product engineering standards include design standards, test standards, and the utilization of standard parts and materials. In the design standards category, there are many standards associated with the product package layout, most of which are local, voluntary standards. During the design there are drafting standards, basically established by the SAE Drafting Standards Committee with modifications, as necessary, to handle local requirements of drafting. Since product drawings are the prime method of communicating product specifications, company standards for drafting must be adhered to explicitly. Many industrywide standards emanate from technical societies such as SAE which distributes standards information like the SAE Handbook. Other standards that must be adhered to, without exception, are the State and Federal obligatory design standards that have been adopted by law. These standards are many,

covering such things as intensity, location, and configuration of lighting; product safety standards; and exhaust emission standards.

Wherever possible, standard parts and materials are utilized where a high degree of integrity and interchangeability exist at minimum cost. These basic standards, however, are supplemented by published company material standards which further define performance, material content, and physical characteristics in a manner suitable for quality control inspection. There are as many as 2,500 Ford Motor Co. standards covering items such as fasteners and bearings; metal sheets, strips, and bars; and thermoplastic and thermosetting plastics.

To assure that products meet the design requirements of performance, test standards are utilized where the engineering standards indicate performance. Test standards establish the methods and procedures for checking and reporting this performance. In this category there are laboratory test standards covering tests of components and complete vehicles, such as the laboratory fatigue and performance testing of suspension components, and the analysis of exhaust gases to assure that exhaust emission standards are met. Also, complete vehicles are placed in a chassis performance laboratory where input frequencies, tape controlled to exactly duplicate road conditions, can be run on a 24-hour basis without a driver. Of interest, too, is the light evaluation laboratory wherein precision equipment reproduces lighting conditions that would be experienced on the road. To assure data correlation, sophisticated vehicle road tests on prescribed surface contours and configurations, scientifically constructed to produce input frequencies of known characteristics, are used to determine product durability and performance.

After incorporating and utilizing all of these standards in the design of a product where interface configurations, performance, and durability are assured, the product design is then released to manufacturing engineering for the design and layout of production equipment required to produce the components of the product which are then shipped to assembly plant locations where the efficient mass production process is completed. In the manufacturing engineering, component production, and final assembly, a completed vehicle is produced with close adherence to product engineering specifications by quality control. In the entire production process there are more than 2,000 manufacturing standards which include process and maintenance material specifications.

Continually, as long as the product is in production, samples of the final product are returned to product engineering for vehicle testing and, where necessary, component testing to assure that product quality performance and durability are maintained.

The many thousands of suppliers in the automotive industry continually have their products validated by quality control for compliance with the engineering specifications that were released in the original product design.

There are similarities to this overall automotive process in the building industry with the possible exceptions being the lack of concentrated central control over all aspects of the building process which would assure delivery of components to the building site that would not require onsite modification for interface compatibility; plus, the much greater variety of local, state, and national building codes that are mandatory requirements which must be complied with in the architectural design and construction process.

Aside from the existence of significant standardization utilization in both industries, I would like to leave you with these thoughts pertaining to a common problem now prevalent in all industries concerning the preparation for answering government questionnaires relative to the metric study being conducted by the National Bureau of Standards.

Nothing has stirred the imagination of technical people in this country quite like the present activity relative to our measuring systems. A natural phenomenon is the tendency to establish and quote opinions based on preconceived ideas about the metric system. Most people know that studies of this nature have been attempted in the past without proper preparation. They were, for the most part, based upon unrealistic estimates and opinions which resulted in astronomical quotations of financial and physical impact. If at all possible, this approach should be avoided in the present study.

If the determination is made that it is in the best interests of the United States to expand the use of SI units of measure in this country, commercial standards organizations, representing the standard parts and materials industry, must move toward the review of existing standards on an international basis. It cannot be assumed that all industries and standards making bodies in this country would be willing to accept all existing metric standards as they are now written. Our present commercial standards, based on inch-pound units of measure, contain many features that are closely related to highly sophisticated manufacturing processes that produce superior products at lower costs. Development of new standards incorporating the best features of existing related standards of the entire international mix of standard parts and materials will be necessary before manufacturers can make any meaningful progress in worldwide interchangeability and performance commonality. This evolutionary process is likely to be a mammoth task for which it would be difficult to project a timetable and related costs for completion. It would depend, for the most part, upon economic motivation.

The simplicity, integrity, and coherency of the SI system of units are well recognized, but too few people seem to recognize the complexities of industrial or commercial standards and the important part they play in our various industries. Anything that can be done that will lead to a better understanding of these elements of the problem can be considered a significant contribution to the welfare of our country.

With these thoughts in mind, the metric involvement should not be overloked in the development of new modular construction standards.

# British Experience—Dimensional Coordination

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Taking full advantage of the opportunity for meaningful change afforded by the current changeover to metric, the British construction industry is accelerating its process of industrialization, the initial emphasis being on dimensional aspects of component building. The formalized approach to this task is explained with special reference to compatibility with international agreements on modular theory, the need for wide component design interchangeability, the role of public sector procurement agencies and the reactions of component manufacturers.
Key words: Component building; industrialization; metric.

## 1. INTRODUCTION

It is important that the contents of this paper be viewed in the context of the nature of the British construction industry. Not only is this industry an extraordinarily dispersed thing comprising many very small units in the contracting and manufacturing sectors along with 20 or more different design disciplines and a whole host of user organizations, but, being so diverse in nature, it is also an industry that tends to be used as an economic regulator by government. Government's own role is significant in so far as it controls something in excess of 50 percent of the output of the industry. Not only do these conditions produce an industrial climate which one would assume not to be very receptive to changing technological ideas and methods, but they also militate against the swift and proper dissemination of ideas and information.

Nevertheless this moment does happen to be a time when the British construction industry is undergoing quite radical change. The change has a number of facets, the two primary of these being an economic regrouping of smaller firms into larger viable units and a time of technological change with the advent of system building and its successor—component building. These changes are made possible by the very close cooperation between Government and industry and it is hoped that one of the byproducts of this paper will be a demonstration of the way in which the different sides of industry can work together on a national plan for change which is not imposed by law but is simply based on voluntary democratic agreement.

## 2. BACKGROUND

### 2.1 A Changing Technology

Largely due to the rapid loss to the industry of the craftsmen upon whose efforts its fortunes traditionally used to lie, the British construction industry is undergoing a process of industrialization. One of the recognizable stages in this process was the advent, a few years ago, of system building which, perhaps because of a lack of experience in handling such innovations, was allowed to grow to an uncontrolled state of proliferation of closed systems. The organization of suitable large markets for such systems was too long delayed to enable all but a very few to be salvaged, for by the early months of 1965 there were in existence in the United Kingdom some 300 closed systems for house buildings alone for a total housing program of well under half a million units.

It seems most logical that this state of affairs should have lent itself to a solution based on the production of standard interchangeable components. Only a handful of the systems could offer a fully comprehensive service embodying in the same package the building shell, services and fixtures, and fittings. The move toward component building saw the start of open systems for the United Kingdom building program.

Such a time of change was clearly also a time to review the performance-in-use requirements of building products and components and, in view of the component interchangeability requirement, emphasis had already been given by 1967 to the need for dimensional compatibility. Several years before this, the British Standards Institution (BSI) had been closely involved in a study of the European Productivity Agency on the subject of modular coordination in building. This study brought together the work of the Modular Society of Great Britain and the International Modular Group. The studies undertaken and the agreements which subsequently followed have since been ratified in the form of appropriate British Standards and International Organization for Standardization (ISO) recommendations.

### 2.2 Opportunity

The agreements on modular coordination which flowed from the European Productivity Agency study formed the theory of the dimensional discipline which had yet to be applied in any meaningful measure in practice. The theory was made widely available throughout the world to any manufacturers or designers who had an opportunity of applying it, but this

was not really producing the coordination which is essential if modular coordination was to be made to work. What was generally lacking was a broad opportunity for applying the theory in a practical way across the whole spectrum of building products and components.

For the United Kingdom such an opportunity was set in 1967 when the construction industry decided, against a tight program, to change to the metric system. In other words the industry had committed itself to making considerable changes in the dimensions of building products and components and it was only logical that if such changes were to be made, they should be fully rational and coordinated. It therefore came about that, as an integral part of its change to metric, the industry decided to adopt on a very wide and all-embracing scale the dimensional disciplines implied by modular coordination.

### 2.3 Program

The metric change program which is being used as the vehicle for dimensional coordination lays down what amounts to a 2-year period of general preparation ending January 1, 1969. From that date, and lasting for approximately 3 years, designers of buildings and the built environment, civil engineers, etc., would be expected to change from imperial design to metric. The percentage of design being done in metric in the early months would be quite small but the objective would be that all new work would be designed in metric after 1971. Wherever appropriate, design in metric would be synonomous with design to incorporate metric dimensionally coordinated building components.

Turning to the construction site, the plan here is a repeat of the 3-year changeover advocated for design, only the start is to be on January 1, 1970, leading to a situation after 1972 whereby all site work would be carried out in metric measure. Most of the training, retraining, education, labor and contract preparation problems seem to lie mainly in the contracting sector of the industry, whereas the problems relating to the integration of metric dimensionally coordinated components lie primarily in the design sector.

The most difficult changes are clearly to be found in the manufacturing sector. And although increased costs due to retooling are inevitably passed on to the consumer, the product and component manufacturer has the first and most grave decision to make in view of the substantial design changes required by dimensional coordination. The manufacturer needs to know two things: First of all he needs assurances that having made a start on production for the new metric ranges the market will be properly organized to receive them, and secondly he needs to know the dimensional nature of the ranges of newly sized components that he is required to produce. In order to allow time for the market to develop following changes in the design sector and also to allow BSI adequate time to work out the dimensional information upon which new product ranges will be manufactured, the start for manufacture of products and components is not scheduled to begin until January 1, 1970. This is not to say that in a number of instances a start is not already being made where dimensional advice and information is already well advanced.

Most manufacturers are gearing their production changes to a 1970 start, by which date the degree to which new building projects will incorporate a substantial amount of newly sized dimensionally coordinated components will have begun to grow. Thus toward the end of 1971, there should be sufficient newly sized products and components available to insure that all new building projects can have a high content of dimensional coordination realization.

Whereas it is not intended to be overdogmatic or perfectionistic in regard to this program of change, it is significant that the agreed target date has been set at December 1972, by which time the bulk of the change to metric dimensionally coordinated building in the United Kingdom will have been achieved. In reality it is possible, if not indeed probable, that sufficient progress will have been made by January 1, 1972, to insure that all that is required thereafter is more in the nature of a mopping up operation.

## 3. PROCEDURE

Just as BSI was entrusted with the broad task of laying down the metrication program, so the same Institution has been charged with the work of producing the dimensional (modular) coordination recommendations.

Although the procedure for working out these recommendations at BSI is sufficiently flexible to allow for amendement as work progresses, a countdown process in the form of eight stages was established quite early. The broad headings under which the work is being phased, plus approximate dates of completion or intended completion, were published in PD 6426, "Steps to basic spaces for building components," and are as follows:

Stage:

1. Establishing the theory (BS 4011) ---------- 1966
2. Metric change (PD 6030) ---------------- 1967
3. Dimensional framework (Controlling Dimensions, BS 4330) ------------------ 1968
4. Arrangement and priorities (PD 6432—Product and Component Lists) -------- 1968–69
5. Detailed planning (PD 6249) -------------- 1967
6. Dimensional recommendations (PD 0000) ----- 1969
7. British standard product ranges (various BS's) ---------------------- 1969–72
8. Production ---------------------- 1970 onward

The above eight main headings are discussed at more length below:

### 3.1 Dimensional Theory

The production of BS 4011, "Basic sizes for building components and assemblies," was most timely set in 1966. Its publication allowed the planning for metric change to be used as an opportunity to embrace the wide-scale application of this particular standard.

The standard sets out a series of preferences starting with 300 millimeters as the first increment of size.

The second increment (also the internationally agreed upon basic module) is 100 mm. After the first two preferences, the two lower preferences of 50 and 25 mm, are put forward but are limited in both cases for situations not exceeding a total size of 300 mm and further limitations are imposed relating to economic necessity. It is important for us to note that whereas there is a difference of terminology between the United Kingdom standard and the ISO recommendation on the same subject, it is not expected that this will give rise to differences in practical application. The United Kingdom, at the time of publication of BS 4011, preferred not to use the term basic module and multimodule, but it will be noted that the second preference of the standard is in fact the ISO basic module and the first preference increment is the first ISO preferred multimodule.

### 3.2 Metric Change

Perhaps enough has already been said about the opportunity afforded by the metric change program as a vehicle for the practical application of dimensional coordination. It might be interesting, however, to recount that, in all probability, the construction industry, a domestic-based industry little given to export, would not have found a straightforward change to metric a very attractive proposition had it not been for the attachment of the dynamic program of dimensional coordination. Prior to the metric change opportunity, the application of dimensional coordination based on the 4- and 12-inch theory had been limited to only one range of products (metal windows) where any real success could have been claimed. Clearly, to await the casual opportunities that might arise year by year in order to make inroads into dimensional coordination would have been a 20- or 30-year process had it not been for the once-and-for-all opportunity afforded by metrication.

The reason why the construction industry was the first United Kingdom industry set itself a plan for metrication lies in the self-realization of that industry that it could both act as a catalyst for all other industries and, by setting is own plan, avoid piecemeal changes as dictated by its many and various industrial clients.

### 3.3 Dimensional Framework

Having established the broad principles against which products and components were to be resized, it became a vital requirement that building designers indicate their willingness to accept design disciplines necessary to make full use of the newly sized building products. This entailed considerable anthropometric, ergonomic, and other user requirement studies encompassing all building types about which data could be collected.

The degrees to which the requirements of BS 4011 could be applied then were established to give what we now call "controlling dimensions" (e.g., floor and ceiling heights, the spacings and widths of structural zones, intermediate sill and door head heights, etc.).

These dimensions are cited in BS 4330, "Controlling dimensions in building," and, while under each broad building type specific preferences are shown, the degree of coordinated requirement across all building types is quite considerable. It is hoped hereby to move fairly quickly out of the era where certain types of buildings bred their own particular components simply because of a special notional functional need. The initiative for these user studies was taken by the various government departments and agencies which are responsible for research and development in building. Already feasibility exercises are being carried out on development rigs which contain full-size building units under dimensional examination.

Following submissions to BSI from government sectors, the BSI procedure of obtaining comment from the whole spectrum of the industry was utilized to get in particular the private, commercial, and industrial building sector dimensions. Returns on controlling dimensions were even forthcoming from the agricultural sector in respect of buildings for livestock occupation—information which temporarily threw many of the BSI committeemen who were deeply immersed in the modular terminology for buildings for human habitation and function.

Already it is necessary to apply these BSI dimensional recommendations in most building designs if loan sanction is to be achieved where expenditure of public money is concerned. In this way we are seeing a very clear market buildup whereby the newly sized components shortly to be produced will find ready use.

### 3.4 Product Lists

An early need of BSI was to identify those products and components in building which were required to be dimensionally coordinated, those which simply required to have sensible metric sizes and those products which might be considered practically free from any dimensional restraint. In addition to this information (essential to the individual manufacturer where his own company program is concerned) it was also required to show which dimensions of a given component were the ones likely to require coordination and which dimensions were relatively free from dimensional restraint. Finally it was necessary to group components in such a way as to clearly indicate how one type of component is dimensionally dependent upon another (i.e. window and cladding units).

PD 6432, "Arrangement of building components and assemblies within functional groups," is an attempt to satisfy all these requirements. The lists are based upon functional groupings which are explained by the following group titles:

- FG 1 Structure (columns, beams, trusses, etc.).
- FG 2 External Envelope (windows, panels, roofs, etc.).
- FG 3 Internal Subdivision (doors, partitions, floors, etc.).
- FG 4 Services and Drainage (heating, electricity, gas, water systems).
- FG 5 Fixtures, Furniture, and Fittings (baths, sinks, WC's, counters, equipment, etc.).

The value of listings of this sort spreads well beyond the dimensional studies currently being undertaken. It is hoped that the whole United Kingdom program of performance requirements studies now generally

underway can be linked to the subdivision of building in this form. This larger plan of reappraisal also involves BSI in terms of setting national performance requirements standards and pioneering the testing and assessment schemes required to implement the standards.

### 3.5 Planning in Detail

At the same time as work was taking place on the above listings, it was also possible to indicate with some precision the detailed timing whereby dimensional work should take place right down to decisions for individual products. BSI issued a network analysis PD 6421 on the subject. Following the earlier stages of the process, it was necessary to issue broad dimensional recommendations covering all five categories and subcategories of interrelated components and finally to make specific selection from these recommendations for individual products. Manufacture to these specific selections (or ranges) would of course follow thereafter against the program requirements of BSI PD 6030, "Program for the change to metric in the construction industry."

It was found necessary at this stage to clearly differentiate between spatial recommendations, that is to say design spaces, and actual product sizes. Between the stages for broad dimensional recommendations which deal with the design spaces to be allocated in buildings for different types of components and the selection therefrom of actual products ranges, lies a great deal of work on the dual problems of joints and tolerances. These are dealt with at a little more length in the next stage of the process.

### 3.6 Dimensional Recommendations

These recommendations, largely based on the previous standards BS 4011 and BS 4330, cover the following subjects of essential dimensional study:

A Matrices of functional basic spaces required for components and assemblies in all kinds of buildings.
B Principles of combinability (i.e., the theory of combinations of numbers).
C Urgent advice on dimensional controls over joints and jointing techniques.
D Specific advice on the control of tolerances both in product manufacture and in site assembly.

The first part A of these recommendations provides sufficient information for manufacturers in a specific group to select product ranges for themselves against statistical information indicating preferences on the part of users. There is little doubt that these recommendations will have to be amended in some measure as time goes by, but they do represent a fairly firm statement of intent on the part of the building user and, therefore, present the manufacturer with a pretty clear indication of what his future production range must be.

In the spirit of interchangeability principles which underline the whole move toward dimensional coordination, it has been found necessary to provide manufacturers with guidances on how the combination of limited ranges of standard products can give fairly wide flexibility in order to meet wide ranges of requirement B. An example here could include the combination of a 600- with a 700-mm-wide unit of partitioning to give 100 mm flexibility from the Dimension 2.4 m and nine 100-mm. increments below that. It is equally important to note that a functional space itself should be interchangeable within limits, so that the function of partition might be replaced by the function of physical penetration (i.e., door) or visual penetration (i.e., window) within the disciplines of component building design.

Work on joints and jointing C has been accelerated recently both in the Building Research Station of the United Kingdom Ministry of Public Building and Works and also in the code of the practice committee on the same subject at BSI. At little risk to ultimate performance standardization here, the dimensional aspects have been brought forward to fill an emergency need at this moment in time and wherever possible, manufacturers are being advised of what restraints should be made in the dimensional aspects of jointing technologies associated with their products. To dimensionally coordinate the design spaces in buildings and to do a similar job on components would be rendered useless unless the jointing allowances between components were similarly exposed to restraint and control.

BS 3626, "Recommendation for a system of tolerances and fits for building," is currently being updated to provide manufacturers with an even more explicit treatise on the control of accuracy in the manufacture of building products D. A new draft code of practice has just been issued by BSI dealing with the whole subject of the control of accuracy on the building site. These points need to be taken into account by a manufacturer when trying to determine, not only the ranges of size for his component, but also the individual work sizes to which production must be geared.

### 3.7 British Standards for Products

With all the above six stages complete, it should then be possible for the BSI Technical Committees concerned with individual products and components (there are several hundred of these) to determine the metric dimensionally cordinated ranges of size and manufacturing data for their new products. As mentioned previously it is possible in some cases for manufacturers to move ahead to the production stage without awaiting the final endorsement of all the previous information by a BSI technical committee. However, many manufacturers are conditioned to accept the existence of a British Standard as being the final authority against which they can manufacture in confidence, and it is therefore an essential phase of the process in the United Kingdom that all these several hundred product and component standards be presented in metric form taking full account of the stages of study outlined here.

Indeed in some senses the existence of these British Standards is more crucial than this. In January 1968, the Ministry of Housing and Local Government in the United Kingdom (responsible for public housing programs) issued the requirement that by the end of

1971 all schemes submitted for loan sanction approval would have to take account of metric British Standards for new products and components. Thus the voluntary process of metric change is being given some teeth in the form of requirements, against which finance is to be secured for building such housing schemes, and this also illustrates one of the many ways in which the United Kingdom Government is playing its own part in the whole program.

### 3.8 Productions

The final stage is of course that of producing the new components and marketing these. In order to make their availability known to designers, a national list is being kept at the London Building Center. Throughout the program of change, government departments together with the Royal Institute of British Architects are issuing facts and figures relating to the volume of design work being carried out in metric and the degree to which these designs will embody newly sized components. Therefore, almost on a day-by-day basis, manufacturers will see the detail of the market buildup.

### 3.9 Progress Generally

The metric program is kept under regular review, and recent close scrutiny has indicated that the plan is being met. Numerous large building projects are already nearing the end of the design stage, and in one or two instances construction work has already begun well ahead of the metric schedule. A recent survey of the housing field indicated that more than 30 percent of housing schemes now on the drawing board were being prepared in metric embodying the requirements of dimensional coordination.

As other industries and sectors of the economy begin their own changes to metric, this reacts upon the construction industry plan in a very favorable way. In so far as these other industries and sectors make up a substantial part of the construction industry's clientele, the proportion of clients requiring metrication as their own wish increases quite markedly.

## 4. DIMENSIONAL COORDINATION—INTERNATIONALLY

As we have seen, the agreements on modular theory in the United Kingdom are compatible with those achieved to date in the International Organization for Standardization. What progress, therefore, is being made in ISO on the practical application of modular theory? It may be important to appreciate here that only in those countries where current plans to change to the metric system are in operation are there likely to be found programs of dimensional coordination which can deal with a subject on a very wide and dynamic basis. For those countries where metric is well established and the principles of modular coordination have been known for some years, there is little opportunity to attack the problem of coordination of sizes on a sufficiently wide front to give a real feeling of revolution. The term evolution is probably more appropriate for these countries which form the bulk of the participating members of ISO/TC 59. (the ISO Committee concerned primarily with dimensional coordination in building).

It was with some considerable enthusiasm, therefore, that a year ago at the plenary meeting of ISO/TC 59 in Milan a new subcommittee (SC 5) had its first meeting to consider the method of work appropriate to ISO for the practical application of modular coordination. With leading proposals from the United Kingdom, considerable progress was made at that meeting, and subsequently in the setting up of two further subcommittees, SC 6 External Envelope, Structure, and Internal Subdivision and also SC 7 Services, Fixtures, and Fittings in Building. The terms of reference and methods of work for these committees, with SC 5 acting as cordinator and progress chaser, follow very closely the procedures that apply to the United Kingdom program.

In addition to the specific work on component ranges and dimensional controls to be tackled in these three new subcommittees of ISO/TC 59, a working party of SC 5 is to study the whole problem of joints and jointing disciplines, and work is being accelerated in existing subcommittees of ISO on the subject of tolerances and fits in building and the all-important subject of terminology. We can therefore see that the same pattern of development that is currently being pursued in the United Kingdom also seems to have found favor as being appropriate to ISO's work. The United Kingdom is most anxious that no wide time gaps are allowed to develop between agreements reached in BSI and the wider ratification of these agreements following discussions in the appropriate ISO committees.

It has been shown in ISO/TC 59 that dimensional recommendations for some building components can be readily and relatively painlessly achieved. Already there is an ISO recommendation dealing with the subject of doors and door sets. This recommendation is largely an agreement on the coordinating dimensions of the components in question. If the United Kingdom domestic program runs in parallel with that now being undertaken in ISO, the prospects for the wider trade in relatively large and sophisticated building components across international frontiers certainly looks good. In view of his unique opportunity for applying dimensional coordination in one large package at home, the United Kingdom manufacturer has reason to hope for some initial commercial advantage when it comes to export, but he will soon find competition fierce as foreign producers recognize the advantages of manufacturing dimensionally coordinated components and find readymade markets throughout the world—including a very well organized and ripe United Kingdom market, where building designers will be showing complete favor to the metric dimensionally coordinated product.

## 5. CONCLUSIONS

For an industry of complicated composition, traditionally minded and still far from adequate industriali-

zation, metric change is a heaven-sent chance to compress into a 5-year period an amount of technological progress which otherwise would surely take 25 years to achieve. While the Système Internationale (metric system) itself will undoubtedly bring advantages to construction and building procedures, it is the attachment of the coordination of dimensions as an essential prerequisite of industrialization that provides the greater enthusiasm for the change.

With its program currently on schedule, it is perhaps a remarkable thing that from one of the least industrialized industries example is being set to the whole of British industry in this exacting process of metric change.

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# The Danish Component Approach [1]

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This presentation deals with the advantages of the component approach such as developed in Denmark. Of particular importance is the concept of catalog building, based on catalogs of coordinated components from which many alternative building designs may be fabricated, and the procedures and standards necessary to produce such a catalog system. In this context, special emphasis is put upon the new concept of multipurpose buildings, typification of joints, tolerances, and trade catalog presentation.

Key words: Catalog building; coordinated components; precoordination.

I have the impression that many people today look at building as a quite complicated thing. Some expect a creative genius to provide a brandnew solution; others look in vain for the means to break the seemingly vicious circle of tradition.

I fully believe in commonsense which tells us that because component building has been good for ages, it might still be so—whether the job at hand is a simple wooden hut with simple wooden windows surrounds, or a magnificient public building with glorious marble window surrounds. It is, by the way, quite unnecessary to try to define what a component is. There are small and big ones, some are more prefab than others. The main thing, in my opinion, is to try to expand from using the components we have been using for so long, such as basins, windows, and doors, to using components for the rest of the house. In my own country, Denmark, we were very lucky when we attempted this component approach.

We started with a national law. This law made it possible to put provisions which furthered the use of prefab components into building regulations. Regulations which require that rental housing shall be planned in agreement with modular rules for building set forth in some Danish standards are based on this law. Please note that the first step of modular dimensional coordination (in Denmark) was only made compulsory for rental housing. The standards referred to state that we have a basic building module (M), equal to 100 millimeters, and we have a planning module of 3 M. That's all. So, the interpretation of this stipulation of the building requirements was left rather free.

We have chosen to understand the building act to mean that projects must be designed so as to assure that the greatest possible number of modular components may be used. It is not modular coordination for its own sake, it is modular coordination because we want to use as many prefab modular components as possible.

We say that projects must be modular. We can require that, but we cannot require that everyone use modular components. The kind of component which will finally be used is chosen after economy has been considered. In quite a few cases it may be more economical, for example, to pour concrete instead of using prefab concrete components. We can only require that the project be modular, so that we may use modular components.

In this connection, I should like to add that there is a further reason for sticking to this formulation. We have found in larger projects that there is often a 10-year period from the moment someone gets the idea to build until the last tenant has moved in. During this time, quite considerable changes may occur in design, construction methods, and also economic relations to design. We have had many cases already where the first 100 or 200 apartments were cheaper when quite conventional building methods were used, and the second, third, and fourth stages were cheaper when prefab components were used. In this type of situation, where changes had to be made after we were underway, it is quite evident that we saved a lot of money by having required that projects be modular. This means mainly, that we are able to change easily and substitute something made onsite with a modular prefab component. If the project is not modular, we have to redesign the whole project to do this.

In plain language, our main aim is to use as many catalog components as possible. Achievement of this aim has been facilitated by the fact that there is a tradition in Denmark for using components. About 800 years ago, our old farmhouses were constructed with precut pieces of timber. So, what we are doing today is really much the same—component catalog building. Only today we are doing component building under quite new industrial conditions.

About 25 or 30 years ago in Denmark, just before the outbreak of World War II, an all-around architect-engineer knew by heart about 300 materials and constructions. It is difficult to define exactly what is meant by a material or construction, but he had about 300

[1] Editor's note: The illustrations used by Mr. Blach are not reproduced and the transcript of his remarks has been edited to eliminate references made to slides. The editor takes full responsibility for any lack of clearness that may have resulted therefrom.

possibilities to choose from. When we checked again, just after World War II in 1947, the number of possibilities had gone up considerably to more than 4,000. The next time we checked, it had gone up to 15,000, and the last time we were able to check, even in a small country such as Denmark, it was past 100,000 possibilities.

Where we are today, I do not know. With the new possibilities provided by light metal alloys and by plastics, we must have passed a quarter of a million possibilities. At the same time, production and other conditions have undergone radical changes. For example, building materials research has changed considerably. Many of the old trades and skills have also changed and boundaries between well-known trades have broken down. Finally, not to be forgotten, completely new requirements as to public activity are now popping up.

I should like to talk for a moment about standardization. Until recently, standardization was used to bring order to a field that had grown out of hand or it was the standardization of desirable, foreseeable, future trends. The standardization we are referring to now will carry out our modular building projects. For these projects we need components on the market, and we need something to govern the design and manufacture of such components. Therefore, we have had to start the whole thing by making up new standards. By far the most important among these are the various dimensional standards.

This brings me to the first very important tool we have in the industrialized building process, "dimensional coordination." It can be explained in many different ways. I am a little bit astonished, being a Dane, that it has not been a greater success in the United Stated where the whole thing really started about 40 years ago.

The introduction of a common measurement was the beginning. Over the ages we have had several things, inches, feet, the brick, as the basic unit of measurement. But, now it was finally proposed that all over the world there be one common basic unit of measurement. The advantage most often mentioned of having one unit of measurement, dimensional coordination, is that we can avoid cutting sheets, pipes, etc., so there won't be so much waste on the building site. In connection with dimensional cordination, it is necessary to take the broad view and not forget any of the many advantages it can provide. To take a broad view brings you to the problem of preferred sizes. It is generally acknowledged that if you have a functional component of some kind you want it to become modular, you have to amend the dimension at least a little bit. This costs money.

At this point, some people will say that this makes modular building too expensive. But, if we take the broad view, is this really so? For example, in an office building, the total expenditure over the lifetime of the building, would be about 92 percent for salaries, 6 percent for services and maintenance, and only 2 percent for initial building costs. Of the initial building cost, the major part can easily be services. So, if we talk about amending the sizes for the structural components of the building, we are really only talking about adding a little bit to a fraction of the total cost for this building over its whole lifetime.

As a result of the broader view, we have developed a Danish standard recommendation containing a series of preferred dimensions. These preferred dimensions have certain advantages mathematically. This new standard has meant a lot. Quite simply, it has provided us with two things: Preferred dimensions which make production and manufacturing more economical for the producers; and at the same time, preferred dimensions which have the characteristic of being able to be divided in more ways than most other figures and dimensions that could have been selected. This means that the practicing engineer or architect will have a much higher degree of creative freedom than he would have had with other preferred dimensions.

The result of our approach is that you will find series of prefab modular components both for high- and low-rise housing on the Danish market. Many prefab modular components are manufactured based on Danish standards or Danish standards recommendations.

The component approach has given us one more economic advantage. Usually, in what we call the old way, the prefab factory produced a closed system. A big investment was required, and such a factory, even if it could produce everything itself, which it very often did not do, was able to produce only very few house types. By far, not enough to cover the demand.

By using the component approach, we have been able, with a much smaller investment, to produce various dimensionally coordinated components. These components can be put together in many different ways to form many different kinds of housing design.

How can anyone find out how to detail or to design a modular component? For the first big modular project we had in Denmark, project design and component design went hand-in-hand. But, when the first projects were over, modular component production went on and manufacturing of new types of components was also started. The designers and manufacturers had to program the field of applicability for the components. This subject of definition of the field of applicability is most important. If the field of applicability is defined in a very limited way, the job for them is usually easy, but the market will also be relatively small. On the other hand, things can go to the other extreme.

We can approach this a bit more systematically if we look, for example, at exterior walls and define the field of applicability so narrowly that we say it is enough that these components can be used for a straight exterior wall. Then, the job at hand is easy, but the market will be restricted. On the other hand, it is evident that if we want to be able to use a prefab component in all types of strange assemblies, it will be tough work detailing and manufacturing such a component.

In Denmark, we have found out that the first assembly to be solved is usually two components in

a row. The next is usually the outgoing corner, and the third assembly, the ingoing corner. This seems to be extremely simple, but if you check systems actually on the market, to your astonishment you will find that only comparatively few of them have the third ingoing corner solutions build into the system.

In principle, the wider the field of applicability for a component, the wider the market. But, also, the more work you have to put into developing the component.

We have no special difficulty, in Denmark at least, in pressuring manufacturers to do this work. Working their way through more and more modular details, they develop a commercial interest in doing so. They widen their market with every single detail for which they work.

For component catalog building, we stress the importance of working in what we call the field of application because so much is decided today on the drawing board. In the old days, we could cut into things and we could really create buildings on the building site, but the moment we approach prefab component building for good, we must recognize that the building is completely finished when the design has left the drawing table. The building will look exactly as imagined by its creator.

Therefore, it is on the drawing board that we decide how future generations are going to live. If we make our components the right way, we will be able later to put them together in a creative way, making building and building environments as meaningful as those in the old days. If we, on the other hand, design components with a too limited field of applicability, they can only be put together in monotonous rows of very simple buildings.

Fortunately, there is no doubt about the trend, more and more will be required from the components. They should be created with wider and wider fields of applicability.

The first tool we had for component building was dimensional coordination; the second tool was the performance concept. I shall not go into this to a great extent since much work is being done here in the United States. I would just briefly mention that we try to get down on paper, not how components should be, but how they should be able to perform. We try to aim as high as possible when we formulate our performance specifications. If we do not have the right policy, the money, or the technology to get the right solutions, then for the time being, we get along with something less. But, we try to aim high and to be able to revise at frequent intervals the day-to-day solutions. In the performance concept a very important thing is the development of new testing methods. This is really the biggest workload and by far the most expensive thing in connection with the development performance requirements and performance specifications.

We need to reevaluate many hundreds of old testing methods which we have relied upon. Quite simply, we must do this because they are not performance based. We need new, performance-based tests. There is only one more thing that I should like to mention in connection with the performance concept. This is that the whole purpose is to make specifications, or regulations, permit more innovation than before. Therefore, it is really necessary to use fantasy when trying to work out performance specifications. An awful lot of imagination is needed if we want the performance concept to work.

Yet another tool for component building which we had in Denmark was the government initiative. We had the usual vicious circle that no one would break. No one would take the initiative to invest. The Government made up a 4-year plan for all of the 8,000 units and promised industry that over a 4-year period, 2,000 housing units a year would be built using only prefab modular components. The response of the industry to this initiative by the Government was very positive and immediate. A few years later, you could even find statements from the bigger firms that the official initiative had justified establishing new highly mechanized factories.

These were the tools in our striving to obtain component catalog building. Next, I should like to briefly mention a little about the work that must be done. The greatest amount of work to be done involves joints and tolerances. The development and accuracy of joints is really a very big problem. It is a rather complicated problem but one we have to solve for the whole series of components if we are to be able to build in a flexible and valid way. This means that we have to solve the problems of accurate joint detailing, and so on for all the types of joints found in components.

As an example of how wrong the whole thing can turn out, in one case, prefab brick components with a backing of lightweight concrete were manufactured to a very high degree of accuracy. The manufacturer, however, had not yet learned how to put such components together with adjustable bolts. He just put them on in the way he had always put up bricks and the result was completely impossible. In only 4 months time, the firm went bankrupt.

Some good work is also being done. Big concrete components, with the weight of 2 to 3 tons, are being manufactured to tolerances of plus or minus 3 millimeters and dimensions of from 2 to 5 yards. To control accuracy, some quite expensive machinery has been built. For instance, floor slab components about 40 M long and 27 M wide, with 2 M thickness are being measured with electronic feelers. By using this method, we can control linear measurements and form tolerances as well. I mention this because the whole thing, dimensional coordination and component building, would be to no avail if we could not control the tolerances.

We have to some extent reached the point where we can say we have catalog component building in Denmark. It is quite common at any one project in Copenhagen, for example, to find big components with name shields from firms all over Denmark. Denmark also receives components (prefab reinforcement and things like that) from its neighboring countries.

Earlier, I treated standardization and said a little about definition of the field of applicability of components, but there is still a missing link. We need a way to get the information from the component manufacturer to the practicing engineer or architect. This being the case the literature (the catalog) gains in importance.

If properly presented, the information contained in the trade catalog can be used several times during the design phase of an ordinary project. First, the information can be used when modular details are sketched. Secondly, the catalog can be used to check whether the components we need are available on the market, and finally, if it is a really good catalog, we can find all of the necessary working details. Thus, the practicing engineer and the architect can be spared an awful lot of work.

In Denmark, we have tried to create some standards for presenting the information about prefab modular components. I think we have succeeded in persuading the manufacturers that it is worthwhile to follow our recommendations.

In connection with approval of new components, it is required that information be presented in exactly the same way. This takes the form of description text, drawings, and details. The recommended way of presenting things is exactly what the practicing engineers and architects need.

So, if the manufacturer will follow our standard directions, he will save quite a lot of work for himself and can use the same presentation several times. Some manufacturers have followed our instruction to such an extent that they make a joke out of it, showing far too many different ways a certain component can be used. Other manufacturers take it more seriously, showing the field of applicability, various uses and solutions and all necessary details.

We have even organized this catalog business and have a building center which centrally edits data sheets and certifies that the components shown have been officially approved as being modular. In the case of windows, as an example, data will contain a photograph, the necessary text, the details and the modular sizes in which you can get the window. On the reverse side of the sheet, you are given the field of applicability and the various window holes into which the standard modular window will fit. The manufacturer has even proved through details that he can provide suitable joints for the solutions he says he can handle.

As a last step in the direction of catalog component building, we have taken up work with systems and components that have a very high degree of rationalization. We believe that in a very short time, enough standard multisystem components should be available to cover the whole market in Denmark. However, we are not only concerned with systems and the big components. We also have smaller traditional components like modular blocks in the catalog. In this case, a new modular block was developed. The result is that we can combine traditional and component catalog building. We can erect a modular, rather traditional, block structure and clad it with prefab modular components.

The reason we are very much interested in these more traditional things, is quite simply the economy of the whole thing. We have been able to register that where we once used 22 man-hours per square meter in traditional and completely conventional building, as soon as we started to rationalize we cut down to 15 hours per square meter and when we really started to coordinate things, we got down to 13 hours per square meter. Finally, by using the prefab modular component method, we got down to 9 hours per square meter. Presumably, the next step is that we get down to between 4 and 5 hours per square meter. This naturally indicates that we can save a great many working hours, as expected, by using prefab methods. It also shows that the first very important steps which do not require enormous investment, will give us very big advantages. This is the reason that we are also interested in the more humble kinds of rationalization.

In conclusion, true component building could be done 5,600 years ago with stone prefab dimensionally coordinated components, with no mortar in the joints. And, to my mind, there cannot be much doubt that the catalog component building approach is still feasible and the way of the future. Thank you.

# Precoordination as a Means Toward Greater Productivity and Efficiency in Canada's Building Industry

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The definition by Professor Ceribini that industrialization is a productive method based upon organized and/or mechanized processes of a repetitive character illustrates that industralization is dependent, among other things, upon dimensional standardization. It is logical then to standardize upon dimensions of the products of industrialized methods to take advantage of repetition in production.

A building is an assembly of componens, equipment, and accessories which coordinate with one another dimensionally in the building. Since these components, equipment, and accessories are produced by different methods in different locations it becomes eminently sensible to employ a means of standardizing their sizes and at the same time of reducing variety in sizes. It is thus that effective repetition is established. In Canada the Standard Building Module of 4 inches is being utilized to an ever-increasing extent toward this end.

The adoption of modular dimensional standardization and the use of modular cordination in the manufacture and use of building equipment, accessories, and materials is being encouraged in Canada mainly by promotional and educational initiatives of the Department of Industry, Trade, and Commerce. This activity is based upon the premise that employment of modular dimensional standardization and coordination becomes a necessity if industrialization of building is to develop in an orderly, intelligent manner.

Key words: Building industrialization; modular dimensional standardization; standard building module.

## 1. INTRODUCTION

My remarks this afternoon constitute a report—almost a saga—on actions taken in Canada in the field of precoordination. I define precoordination as standardization that acts as a common denominator among product designers, building designers, and erection contractors in relation to the manufacture and assembly of building components. While I recognize that this definition has both functional and dimensional attributes I shall be dwelling predominantly upon dimensional aspects of building because our initiatives have been primarily with regard to dimensional standardization and coordination. We may have been somewhat pretentious in separating the influences of function and size in this way but our thinking has been that functional matters could be construed to be a building code responsibility while dimensional aspects are primarily the direct responsibility of the manufacturer and the designer.

## 2. PRECOORDINATION IN CANADA

A principal mandate of the Department of Industry, Trade, and Commerce is to improve productivity and efficiency in Canadian industry. It is natural then, since the building industry considered in its total context is Canada's largest industry by far, accounting for about $14 billion or 20 percent of our gross national product, that it should merit special attention within the terms of reference and order of priorities of the Department. The Department is fortunate to have a number of officers who had gained rather extensive experience in the building industry before joining the Government service. Their collective experience was important in helping determine areas of endeavor in which departmental initiatives could proceed.

The Department of Industry's initiatives were not the first in the field of modular or dimensional cordination by any means. Much work had already been carried out by the Division of Building Research of the National Research Council of Canada under the Division's Director, Dr. Robert F. Legget. I am sure that many of you know or recognize the name of this distinguished Canadian whose knowledge, experience, and contributions in the field of building standards ranks among the very highest. Dr. Legget's right hand man in this work was Prof. Stanley R. Kent of the University of Toronto and the Division of Building Research. Professor Kent has undoubtedly contributed more regarding dimensional considerations at the working level than anyone else in Canada. That our building industry is now increasingly accepting and applying modular principles and concepts is creditable to a significant degree to the directional work of Dr. Legget and the educational activities of Professor Kent extending and continuing over the past 15 years.

My Department's subsequent activities vis-a-vis the building industry were undertaken only after rather ad hoc but extensive discussions with influencial and sagacious industry representatives. It was in consultation with prominent architects, engineers, manufacturers, and contractors representative of their professions and industries and also regionally representative of

Canada, that the concept of dimensional precoordination was indicated as presenting a potentially rewarding area of endeavor. Thus it became a major aspect of the BEAM Program.[1]

Decisions reached in these early discussions were based upon the following premises. These, it must be admitted, were rather loosely articulated at the time:

(1) The building industry, to be fully understood, needs to be regarded as the industry manufacturing and using building equipment, accessories, and materials. This is a true definition of the industry, a total concept emphasizing the interdependency of the manufacturing, the designing, and the contracting sectors.

(2) Greater industrialization reflecting greater productivity and efficiency and lower costs was/is necessary for the industry to satisfactorily meet its objectives in Canada.

(3) Orderly and intelligent industrialization of Canada's industry depends to a large extent upon dimensional standardization and cordination. Thus in attempting to encourage greater industrialization as a means toward improving productivity and efficiency, appropriate emphasis on dimensional considerations should be expressed.

(4) Entrepreneurs, whatever their area of endeavor in the building industry, would not willingly embrace standardization and coordination voluntarily in the absence of some indication of lower costs or higher profits or both. Because little tangible data existed in this connection, part of any program of this type had to appeal to entrepreneurial good sense.

(5) A program, whatever its form, aimed at encouraging greater industrialization of building should be related to aggregate economic concepts. That is to say—benefits deriving from gains in productivity and efficiency would ultimately increase the wealth of Canada. This is so because Canada possesses a highly developed market economy in which the prices of commodities are in the long run competitively determined in the marketplace. In this broad context, it seemed immaterial where savings were made.

(6) Because of the economic importance of such a program, the success of the program could be stated to be in the national interest.

Not quite at that time—but shortly thereafter we adopted a definition of industrialization which has since augmented and integrated the above six premises. The definition due to a Professor Ciribini of Italy—freely translated by Mr. Colin Davidson is this: "Industrialization is a productive method based upon mechanized and organized processes of a repetitive character." The conciseness and completeness of this definition seem to us to be eminently sensible. The keys to successful industrialization lie in an efficient way of doing things (a productive method), in mechanized organized processes, and in effective repetition.

## 2.1 How Was a Program To Be Developed and Implemented?

A good base for an onslaught in the field of dimensional precoordination had been created, as I inferred earlier, through the work of Dr. Legget and Professor Kent. For example, excellent literature in large quantities was available from the Division of Building Research library. Supplementing this, there had been a succession of reports from the Economic Council of Canada stressing the need for greater productivity and efficiency in building as an avenue to a more prosperous economy. Also, dimensional coordination had received a fair degree of intellectual assent if only limited practical application. Altogether, when one looks back on the building industry situation as it was then (in the fall of 1966), it is possible to discern that the overall industry climate was receptive to proposals for change. Of course, the term industrialized building was still in high fashion, having been imported from Europe not long before, even though its implications were understood by many different people in many different ways.

And so a program designed essentially to be educational, promotional, and attitude forming was formulated.

At this stage it immediately became necessary to organize formally an advisory committee of industrialists and professionals from both the private and government sectors—representatives of major asociations and regional representation to debate, recommend upon, and approve such actions as were considered essential to the achievement of program objectives. (Roughly the equivalent of the A62 Committee.) Stated broadly, these objectives were to gain acceptance and use of the principles modular dimensional precoordination based upon the standard 4 inch module throughout the Canadian building industry by 1972. In our estimation, this needed to be done to be in advance of the expected rapid development of industrialized building.

The first meeting of the Committee was held on March 17, 1967. After four meetings, held at approximately 6-week intervals, a program of activities was approved. It consisted of organizing and holding conferences and seminars across Canada, and of scheduled literature distribution on a large scale to those who should be interested and influenced. Extensive use was to be made of the national and industrial press and periodicals. In short, the target was to make the importance of dimensional precoordination in the contemporary context widely known and appreciated in as short a time as possible.

Accordingly, a series of six conferences was held in major centers in Canada during October 1967. These were designed to acquaint as broad an industry representation as possible with the values of dimensional coordination. The conferences were successful in that about 1,000 senior representatives of Canada's building industry attended. Four distinguished lecturers,

[1] BEAM—a program for increasing productivity and efficiency in the manufacture and use of building equipment, accessories, and materials.

Professor Kent, Lennart Bergvall of Sweden, Phillip Dunstone of England, and Colin Davidson, then of England now of Canada, delivered papers aimed, respectively, at the design professions, the manufacturing sector, and the contracting sector. Mr. Davidson's lecture "Industrialization and Coordination" had the effect of drawing together the other three contributions by illustrating relationships between the three sectors and how these could be rendered less ad hoc and haphazard.

We have always attempted to represent dimensional coordination and industrialized building as implying rationalization not regimentation—as implying the self-imposition of disciplines and as a means toward cost reduction.

The proceeding of this series of conferences have been published and are available free of charge.

Following upon the conferences, we initiated a continuing series of Clinics of Modular Practice in all parts of Canada. To assist in this undertaking we elicited the assistance of 16 architects who after a short period of training and with the supply of literature, slides, etc., were qualified to act as instructors. Organization of the clinics has been rather informal but the architectural associations and the Specification Writers Association of Canada and their chapters responded well and as of now about 10 clinics have been held with a total attendance of over 4,000. Architects, engineers, managerial and supervisory staffs from manufacturing and contracting companies have participated. Thus a knowledge of the importance of dimensional precoordination and its conventions in design and building has been imparted to a significant number of personnel associated with the building industry.

The industry has since been surveyed and the first edition of a Directory of Modular Building Components has been published. This directory is subject to annual review and should provide a means of analyzing the growth in production of modular by dimensional components. This initiative has ben particularly well received. The first edition of the directory lists some 500 companies manufacturing a wide variety of products that conform to dimensional standards based upon the 4 inch standard building module.

The second edition of the directory, due to be published in January 1970, will have perhaps double the number of companies and a significant increase in the number of listed items. Greater attention will be paid to methods of jointing of components in this issue and appropriate information in this regard will be listed.

### 2.2 Where Has All This Activity Led Us?

Notable successes have been that all Federal Government departments having major responsibilities for building, have since the commencement of the BEAM Program adopted dimensional coordination in their design and construction work. Moreover they are requiring that their consultants also do so.

The Departments concerned include: Public Works; Indian Affairs and Northern Development; National Defense; Transport; Health and Welfare.

A majority of the 10 Provincial Departments of Public Works and Departments of Education have adopted modular dimensional coordination also. Our relationships in this regard with provincial government departments concerned with building have been exceptionally cordial.

Some of these departments such as the Federal Department of Public Works set up their own training programs in order to familiarize their entire design staffs and inspectorates with the subject.

This particular Department also reports that the concept of dimensional coordination has been well accepted within its head office, in its regional offices and by its consultants. It has received many congratulatory messages from industry for assuming a position of leadership in this field.

Several provincial government departments have reported similar reaction to their initiatives. Senior officials from Department of Public Works British Columbia regard the matter of precoordination as being so essential to the future of the building industry that they consider it a responsibility of Government to provide leadership to industry at some departmental cost if necessary. This philosophy is shared by officials of the Department of Public Works of Quebec and to some extent by those of Ontario.

In other respects, the measuring of success or failure of our program has been deficient. We had an excellent opportunity of taking a base measurement of productivity in 1967 and then of measuring growth of productivity and efficiency due to the adoption of dimensional precoordination in succeeding years. Such a device was not, however, utilized at that time but I am glad to report that action is underway and is likely to be undertaken shortly.

In the absence of a universal monitoring arrangement we have had to restrict our activities in this field to a few independent assessments. The first of these concerns the concrete block industry of southern Ontario which up to a year ago predominantly produced nonmodular block with a small percentage of modular block (two complete product lines). The changes in attitude brought about by our program enabled the block manufacturers to announce about a year ago that as of January 1, 1970, they would not produce or sell anything but standard modular products except at premium prices.

After this announcement, the demand for modular blocks—already increasing—rose steadily and in August 1969 occupied about 90 percent of total demand in most plants. Spokesmen for the industry indicate that market demand will dictate 100 percent of modular products before the January 1970 date.

Of more interest are achievements in cost reduction. A random survey of six block producing plants in the Toronto area indicated production cost reductions of 4.8, 7, 11, 12.1, 14.6 percent and one cost increase of 6.9 percent. This latter is attributable to the phasing out of an old plant and not to the increasing demand for modular blocks. When production weightings are applied to the first five observations, the figures average to 10.8 percent. Now the six plants sampled have a value of shipments of some $7 million and assuming

that production costs account for $5 million of this figure, the annual saving works out at $540,000 per year. This figure is significant since the combined activities of our program are costing roughly $50,000 per annum.

The second report is derived from the experience of a leading prefabricator of houses, schools, work camps, etc. It is specifically in regard to school classrooms and compares dimensionally coordinated production in 1969 with noncoordinated production prior to this year. The results of a cost analysis are included in table I below.

| Components | Labor | | Materials | |
|---|---|---|---|---|
| | Percent saving | Weight-factor(/) | Percent saving | Weight-factor(/) |
| Walls | | | | |
| structural and exterior finish | 8.5 | 0.289 | 19.6 | 0.293 |
| Roof | | | | |
| structural and exterior finish | 19.4 | .166 | Nil | .338 |
| Partition framing | 16.7 | .149 | 9.3 | .137 |
| Final finish | 25.0 | .396 | 5.5 | .232 |
| Weighted average | 18.11 | ---- | 8.3 | ---- |

The total cost reduction amounts to 26.41 percent on labor and materials—18.11 percent and 8.3 percent, respectively. Labor and material value included in the total annual output of these classrooms amounts to approximately $4 million. A total cost reduction in terms of labor and materials of > $1 million is therefore being achieved.

These examples may not be completely in keeping with the concept of precoordination. The second example involves closed system industrialization; but even though it is closed, it involves the use of dimensionally coordinated components and thus deserves mention.

An indicator of interest in dimensional coordination has been the number of requests from the professions and industry for literature independent of that distributed as part of the program.

The demand for three of the principal publications issued by the Division of Building Research shows that the average for the 3 years 1965, 1966, 1967 totaled 1,255 copies annually. For 1968 and to date in 1969 the demand has averaged for 3,089 copies annually.

In addition to the above, there appears to be evidence of benefits to be gained in a secondary way from a detailed knowledge and application of dimensional precoordination. This might be termed a catalytic effect. Regrettably it may never prove possible to equate a dollar value to this phenomenon but one is constantly reminded of its validity in conversations with architects, manufacturers, and contractors. Many consistently profess that the greater awareness of dimensions has inspired a disciplined thinking—a discipline which they propose to continue to utilize to whatever advantage they can.

For example, the prefabricator of school classrooms to whom I referred a moment ago has informed me that in standardizing the dimensions of the classrooms in accordance with the modular discipline, his R. & D. staff perceived a way to design a more economical flooring system. Although cost reductions achieved in this way cannot be ascribed to dimensional precoordination, they certainly derive from the discipline and therefore qualify under the heading "catalytic effect."

### 2.3 What of Future Program Activities?

It would seem that in view of the above, the bulk of the objectives set at the beginning of our program have now been demonstrated to be attainable, requiring only a continuation of ongoing program activities for full realization. But during this time industrialization of Canada's building industry has moved ahead, I would judge, rather rapidly. There are four main forms of development:

- Industrialized or rationalized traditional building.
- Total factory prefabrication such as we find in the mobile home industry or the sectionalized housing industry.
- The proprietary closed system.
- Open system development resulting from systems approach research.

These developments coupled with our own activities have led to a clear recognition of a need for a logical extension of the initial endeavors; that of the further and more rapid development of dimensional standards for building components and buildings and for standards anticipating and guiding future developments. This recognition of a rather urgent need has stood out clearly for some time in the deliberation of the Industry Advisory Committee and in discussions with industry and government representatives on the one hand and BEAM Program people on the other.

Now, it is not difficult to prescribe dimensional standards for say masonry products and others of the like, indeed these already exist. It is an interesting digression that the concept of modular dimensional coordination arose from the logic of arranging the larger dimensions of building so that repetitive units, such as masonry units, could be used to form these dimensions without cutting. But such a concept immediately brings sharply into focus the question of joints and jointing methods. The flexible wet-type of masonry jointing overcomes questions of tolerance and makes the modular concept workable without difficulty in buildings constructed with masonry.

But greater industrialization of building will seemingly result in a further transfer of operations from the site to the factory, provided that overall reductions in cost can be demonstrated. (The latter is important in the context of the market economy and its price mechanism.) The further migration of operations from site to factory will in all likelihood mean that larger and more complex assemblies will be made in the factories for transport to and erection on the building site. It seems clear that if a means (such as the standard module) is not utilized for standardizing and controlling the dimensions of such assemblies together with appropriate attention to joint details so that they fit in buildings without alteration as required by the

designer, there will be little possibility of establishing requirements for a large enough number of identical units to make effective repetition possible—a requirement for economical industrialization.

What I am mainly envisioning here is of course the open-type of industrialized building because precoordination has its greatest relevance to open-system building. This is not to say that the proprietary closed system cannot benefit similarily from dimensional precoordination. It seems reasonable to postulate if the closed system is dimensionally coordinated it leaves the proprietor some freedom of choice for the inclusion of brought in components which may be purchased more economically, and the possibility of spinoff business through the sale of standard components from the systems manufacturing processes.

In either event the case seems clear for an efficient rapid method for the development of dimensional standards—a method that would include a recognition of dimensional tolerances and joints.

In this connection we have formed an interim study group representative of Central Mortgage and Housing Corporation, Division of Building Research, Department of Public Works, Canadian Government Specifications Board and the Department of Industry, Trade, and Commerce which has been charged with the task of studying in depth the treatment of dimensional standardization in technologically developed countries. This study will culminate in a report which will contain recommendations on a strategy for future action in Canada in this all important aspect of precoordination.

In addition to this activity, a small group of consultants chosen by the Royal Architectural Institute of Canada are about to commence a preliminary study on generic planning modules. Should the preliminary study indicate that a major investigation in this field is necessary, it is hoped that planning modules generic to identifiable building types such as schools, hospitals, etc., will be identified and will become the accepted standards of the industry.

In relation to these two studies, we have made a conscious decision to separate the influences of size and function in the context of comprehensive meaning of precoordination and as in our past activities, we intend to concentrate on dimensional aspects of the problem. We realize that we are navigating in tricky waters here because a good case can be made to the effect that effective repetition must result in identical products having identical functional capabilities as well as standardized dimensions. We further recognize that it makes a good deal of sense to examine the statement, "that from a manufacturing point of view it may be just as costly to provide a range of functional capabilities within a fixed set of dimensions as to provide a choice of dimensions within a given number of units."

In the above connection because we are cognizant of the value of the systems approach method, we have a vital interest in building programs in Canada in which the Systems Approach to Building concept has been applied. Notably in the Montreal and Toronto school building programs. An integral aspect of these systems developments has been the intelligent choice of horizontal and vertical grid dimensions. See appendix I.

The significant development of the Toronto program is that due to organizational considerations and bidding procedures there now exists in Toronto the capability of producing dimensionally coordinated subsystem assemblies which when combined in all possible ways give more than 13,000 school building systems, some 3,000 of which are less costly than the original budgeted estimates. The inference here is that problems of jointing and dimensional tolerances have been worked out in this system somewhat independently of other functional attributes. Moreover, the solutions appear to have been accomplished at sufficiently low cost to make a marked advance in the whole spectrum of industrialized building in Canada.

By logical extrapolation it would seemingly require only a limited number of similar initiatives in various building fields such as housing, hospital building, and apartment building to arrive at a large family of open-system components which within each field of application would be interchangeable. Whether this is possible in the present industrial and governmental structure and whether it will happen remains to be seen. Certainly it is a concept deserving of serious thought.

Of course this is a concept that if implemented will require a national means of setting standards for testing against performance requirements and granting approval for large and sophisticated subsystem assemblies in terms of both functional and dimensional precoordination.

In the Toronto school system testing and certifying is being carried out by the Canadian Standards Association, two representatives of which, Mr. Dymond and Mr. Shah, are in the audience. Also a new organization in Canada—the Industrialized Building Methods Association I.B.M.A. is aware of the problem. Mr. Joseph Giddens—an architect and prime mover of this association is in the audience also and may wish to speak during the discussion period.

And last—there is an interdepartmental working group on the approval of building components active in the Federal Government. Our discussions in this committee have brought sharply into focus the staggering ramifications of establishing a national approvals body. However, in all our work the uncertainty of success has never been an impediment to taking action.

# Appendix

## CHOICE OF PLANNING MODULES

### (Study of Educational Facilities, Toronto)

As has been suggested, to implement an open building system and to industrialize the building industry effectively, the size of all building products must be dimensionally coordinated.

SEF recognizes the standard 4″ module as defined in CSA A31–1959, as far as it does not impede function. The selection of the module affects both the vertical and horizontal planning grids on which a system can evolve. The alternatives were a two-way horizontal planning grid with an independent vertical planning grid, or a three-dimensional space grid. The two-way horizontal planning grid with an independent vertical planning grid was chosen because it corresponds better to traditional building methods. The horizontal planning grid selected is 5′0″ × 5′0″ (60″ × 60″) and the vertical planning grid is 12″ (1′0″).

(*a*) Horizontal Planning Grid: The 5′0″ × 5′0″ horizontal planning grid was selected because:

(1) It fits accurately to the space requirements recommended in the SEF academic research studies, and it satisfies the Metropolitan Toronto School Boards' ceiling cost formula.

(2) Since it is the largest planning grid which fits the basic space requirements, it reduces joints to a minimum.

(3) The planning grid accepts the 4′0″ fluorescent lighting tube in a variety of arrangements with an adequate allowance for partition thicknesses and other obstructions of the ceiling plan surface. Among major manufacturers of lighting-ceiling systems who were consulted, there were requests, on grounds of economy, to specify 4′0″ fluorescent tubes rather than 3′0″ tubes.

(4) Since the 5′0″ ×5′0″ planning grid has been used for the SCSD project in Southern California and the Florida State School Building Program, a number of building materials based on this planning grid have already come into existence.

(5) It is approved by a variety of structural, lighting-ceiling, partition, and vertical skin product and component manufacturers.

(6) Since the subsystems are commonly used in commercial building, the subsystems of the first SEF building system can be directly applied to buildings other than schools.

(7) The large ceiling grids formed on the planning grid provide a relatively tranquil visual environment.

(8) It appears to have dimensional appropriateness and in particular most partitions aline themselves on this planning grid.

(9) It can be divided into a 20-inch subgrid which has been suggested as a suitable grid in the design of residential high-rise buildings. Materials and subsystems designed to fit this residential planning grid could be used in buildings using the 5′0″ × 5′0″ planning grid.

(*b*) Required Dimensions: Required dimensions refer to the elements of the structure subsystem and are related directly to the planning grid of 5′0″ × 5′0″.

Required dimensions for primary spans: 10′0″, 15′0″, 20′0″, 25′0, and 30′0″.

Required dimensions for secondary spans: 5′0″, 10′0″, 15′0″, 20′0″, 25′0″, 30′0″, 35′0″, 50′0″, 60′0″, and 65′0″.

Spans beyond 65′0″ advance on a 5′0″ increment and will be custom fabricated.

(*c*) Application of the Dimensional Criteria: Planning: All buildings using the SEF Building System have been laid out on a 5′0″ × 5′0″ planning grid. The overall dimensions and form of all buildings are governed by this planning grid. Consequently, all structural plan dimensions and all dimensions of exterior walls are multiples of 5′0″; all changes of direction of wall planes in plan are multiples of 5′0″.

Al changes of direction in plan form take place about a column. The structural subsystem performance specifications require braced bays to stabilize SEF framed buildings. The location of these braced bays will be the responsibility of the architect and engineer for each project.

The SEF Building System is not capable of accommodating cantilevers, either of the structure or of canopies, columns supported on primary or secondary beams, or sloping walls or roofs. Should a demand arise for these structural configurations, future versions of the successful building subsystems may include provisions for these configurations.

(*d*) Building Heights: The SEF Building System is suitable for the construction of buildings up to five stories in height with one floor on grade, four suspended floors and a roof. The full number of stories for the building system has been selected to coincide with the requirements of the National Building Code and represents the point of division between 1- and 2-hour construction.

The First SEF Building System can be used on all forms of building sites and is capable of application to buildings which have varying roof and floor levels within the same buildings.

Clear ceiling heights from finished structural floor surface to finished ceiling soffit are as follows:

10′0″—Most tutorial, library, and laboratory spaces.
14′0″—Shops, music rooms, and some large group areas.
18′0″—General purpose rooms and large group areas.
24′0″—Gymnasiums.

Each of the above nominated clear ceiling heights may also be used for a variety of circulation and service spaces. The required dimensions for the floor and roof sandwich thicknesses are:

Up to 65′0″ clear spans—4′0".
Over 65′0″ clear spans—5′0″.

(*e*) Floor Roof Structure/Service Sandwich: The structure/service sandwich is a grouping of structural, atmospheric, and electrical subsystems integrated with finishing and weatherproofing subsystems, contained between two flush, parallell planes.

This sandwich which may be a "roof sandwich" or a "floor sandwich," includes spatial and depth provision not only for hard elements such as beams, slabs, lighting fixtures, and ducts, but also for "soft elements" such a space allowance for future unpredictable services. The latter may include wires and other cables, and pipes and services for undetermined future functions.

(*f*) Tolerances: All tolerances to an interface plane are negative. Within this negative interface tolerance, manufacturing tolerances will be positive and negative.

In principle, the first SEF Building System aims for a loose fit approach to component integration to allow for the inaccuracies which are common to the building industry.

# Dimensional Precoordination as the Basis of Industrialized Building—Current Status in the United States

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This presentation examines the existing extent dimensional coordination in U.S. construction industry practice. The dimensional system inherent in conventional building is also examined and significant products and practices are listed. In addition, dimensional relationships that are now emerging in various innovative systems are mentioned.

Key words: Conventional building; dimensional coordination; dimensional relationships.

## 1. INTRODUCTION

Construction research programs have been conducted at Battelle's Columbus Laboratories almost from its inception. The Construction Systems, Planning, and Economics Research Division, which has responsibilities in some of these areas, consists of engineers, architects, market analyses, and economists. We are currently involved with new construction methods and techniques: Development of design criteria; development of performance specifications for new products and components; evaluation and development of industrialized building systems; and conduct of conceptual architectural, financial, and planning research. It is an honor to have the opportunity to relate our work to that of the A62 Committee in delivering this paper on the current status of dimensional precoordination in the United States.

## 2. CURRENT STATUS OF DIMENSIONAL PRECOORDINATION

Historically, aesthetic proportions and traditional building methods have been the main generators of dimension coordination. Aesthetic dimensions were highly developed into a series of coordinated proportions by the Greeks and Romans and were again popularized during the Renaissance. The building process has been an important generator of modular coordination as has the optimal size and weight of a component. For example, the proportion of bricks is based upon the shape, weight, and dimensions that are most easily grasped and laid by a mason.

The concept of dimensional coordination of manufactured components in the construction industry is directly tied to the 19th century industrial revolution. The traditional stick method of cutting and fitting each part of a building as a custom craft activity has only been replaced by the rationalized method of building using components and products that are premanufactured and then brought to the site for assembling. One of the earliest examples of industrial-dimensional coordination and interchangeability was the gages for ammunition and guns developed in 1776 by French Lieutenant General Gribeauval. Similar developments in the United States were pioneered by Eli Whitney in 1800 when he produced rifles on the first assembly-line basis. English innovator of dimensional coordination, Joseph Whitworth, commented in 1856 on the effect of standardization in building components:

> Suppose for instance, that the principal windows and doors of our houses were made only of three or four different sizes. Then we should have a manufactory startup for making doors, without reference to any particular house or builder. They would be kept in stock and made with the best machinery and contrivances for that particular branch; consequently, we should have better doors and windows at the least possible cost.

Although modular coordination was introduced in the 1920's, it was not until the thirties that Albert Bemis outlined the idea of a full-dimensional coordination for the building industry based upon the use of components, the dimensions of which were multiples of a 4-inch module. The first standard for modular coordination was adopted in 1945 and the A62 Guide on Modular Coordination that first established 4 inches as the basic module was published in 1946 by the Modular Service Association. Since then, work was undertaken by the Modular Building Standards Association (MBSA) and more recently by the American National Standards Institute (ANSI) under the sponsorship of the National Bureau of Standards.

Currently the supply complex of the construction industry operates as a modified open system. In general, each building component or product is related by standards or tradition into functional groupings. Functional coordination by product type is well illustrated by Sweets Catalogue or Graphic Standards. Coordination of dimensional standards and often performance criteria has been developed within most functional groupings by tradition, individual manufacturers, trade associations, institutes, or government agencies. The membership list of the A62 Committee is composed of over 55 such groups or individuals. Although the A62 Committee has just recently published basic module of 4 inches for horizontal dimen-

sioning, dimensional coordination has been inherent within the construction industry.

Most products, however, are designed to be used in the custom building market where they are field adapted. Architectural and Engineering News recently estimated that cutting and fitting now takes from 5 to 45 percent of construction time. Many products are not universally used or interchanged from one project to another due to lack of coordination in joint design and/or standardize dimensions. Often components are part of a closed system due to the proprietary nature of the building industry and its supply complex. Curtain wall systems and metal building have much duplication, but little interchangeability. Within a closed system, interchangeability is not critical as all components and joints are designed to interface. In open systems, components coordination between different functional groups will allow for the installation of preassembled subsystems even if various manufacturers produce them. Interchangeable components could be removed, relocated, or replaced without destruction of the assembly itself or to other elements of the buiding.

When considering dimensional coordination, one must differentiate between different types of interface connection. J. F. Eden in England has referred to these differences as the "degree of restraint." In lap joints, stacking, or surface mounting, there is little restraint as long as the overall height or length is not critical. However, once assemblies have to fit together where their edges interface, dimensional coordination becomes critical.

The choice of a 4-inch module as the basis for the horizontal dimensioning of coordinated building components and systems conform to most current dimensional systems used in the construction industry. The system module selected in the U.S.A. Standard A62.5 was 60 M or 20 feet. Into this module, the factors of 2, 3, 4, 5, 6, 10, 12, 15, and 20 provide for component coordination. I shall now briefly review these factors and list how they conform to the dimensional system inherent in conventional building.

| | |
|---|---|
| M (4") ½ M (2") | Basis for nominal dimensions of graded lumber, steel, and precast masonry. |
| M, 2 M, 4 M (4, 8, 16") | Standard masonry nominal dimensions for brick, block, and related products. |
| 3 M (12") | Common increment of framing and component materials. |
| 4 M (16") | Accepted spacing for stud wall construction. |
| 5 M (20") | ½ metric module. |
| 6 M (24") | Standard width of precast masonry components (deck) and accepted stud spacing in selected materials. |
| 10 M (40") | Nominal equivalent to the metric module, but has not been widely used in the United States. |
| 12 M (48") | Most common component module for sheet materials, and also used in interior partition and integrated ceilings as planning module. |
| 15 M (60") | Widely used as the basic planning module in integrated ceilings, office layout, and flexible partitions. |
| 60 M (20 ft) | Large enough for a systems module, yet flexible enough for multiple use. It has not been as widely used as the 12-ft. module which is generally used for mobile homes and sectionalized buildings. Currently most proprietary frame and box building systems do not conform to a specific set of dimensions. |

# The Role of Precoordination in the U.S.S.R.[1]

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## ABSTRACT [1]

Building and construction in the Soviet Union are unique activities with regard to: (1) Scale of operations, (2) total organization of design and production under state auspices, (3) methods of finance, and (4) social-economic purposes served. The extraordinary nature of the Soviet building activities arises from historical imperatives and political principles which must be understood prior to examination of the building process.

[1] Dr. Bates' presentation consisted of a rapid commentary on a hundred or so slides. Unfortunately, reproduction of so many colored illustrations is beyond the scope of these proceedings and the transcript is meaningless without the associated illustrations. It is with sincere regret that we can provide only the abstract of Dr. Bates' fine presentation.

# Housing: A Sense of Urgency

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The pressures for providing more and better housing are examined together with the constraints, both apparent and real. Industrialization of production of housing appears to be the obvious solution. Precoordination of components and developing an industrywide open system of catalog building, appears a desirable route to such industrialization.
Key words: Catalog building; housing, industrialization; precoordination.

Wherever I come into contact with the housing scene today I feel a growing sense of urgency. The pressure comes from many separate places. Where these pressures come together and act in concert, something dramatic will surely happen.

Part of the pressure comes from the millions of families who are existing in substandard houses or apartments. In this age of rising expectations, fewer and fewer people are willing to accept substandard housing as their lot in life. If the Joneses' have it, and the Smith's don't, the Smith's want it; and they don't want to wait too long to get it. They are willing to work for it, and given the opportunity, they will work hard to pay for it. They want that opportunity.

Part of the pressure comes from the rise in population. Even if we get underway with a serious program of birth control in the next few years, we still will have a population of some 300 million in the United States by the year 2,000. We cannot really imagine 300 million people in this land of the great open spaces, but we know that as we move toward a population of this size the quality of life will be drastically impaired even if we solve our housing problem.

Part of the pressure comes from the increased urbanization of our society. Increasingly, we live in a manmade world, and if we neglect the amenities, comforts, and compensations, the effect on people will be increasingly severe. Housing is at the center of this problem; not just the immediate living unit, but the entire system for living—housing, services, streets, parks, communications, transportation. But the central problem is housing.

Housing has a special significance in the social revolution which is developing around us. The need for shelter is one of the most powerful psychological imperatives. The concept "home" not only has deep associations of warmth, comfort, and security; it also is part of a man's pride and his sense of status. If a man has a decent place to bring a wife, raise a family, and entertain his friends, he has a base for a feeling of personal worth, and for participation in the community. Force him by economic pressures or poor social planning into an overcrowded hovel, and his value to society declines with the erosion of his estimate of himself.

It is pressures such as these which are generating a new sense of urgency in the housing field. That is why government and industry are taking a harder look at housing problems than ever before. And I think we are gaining some insights which may help to remove the obstacles which still stand in our way.

Some of the problems which are now emerging have been there all the time, but they have been hidden by the complexity of the industry and the traditional building process. Uncertainty, for example, anywhere in the building process runs up overhead and increases costs.

If a builder is uncertain about the number of orders he will receive in the months ahead, he will necessarily schedule his work to keep his people busy. Payrolls have to be met, and if he lets people go in slack seasons they may be hard to replace. So he tends to stretch out work in busy seasons to fill in gaps in slack seasons. It is not the most economical way to build houses, and it makes some customers angry with him, but under the present system he has no choice.

In the same context, he has to bid as high as he safely can on a job because he knows that when it is completed he will have to tide himself over until the next contract is secured. Since most contractors are in the same boat, prices tend to push against "what the traffic will bear."

If builders knew that they could depend on a share of a large volume of new houses they could approach both problems in a more businesslike way.

When a new product is introduced into the construction market—a new material or component—it may represent long-range benefits, but its immediate effect may be to create uncertainty. Consider the building inspector. We complain about restrictive building codes, and with good cause; but the problem goes beyond the code itself. If you want to build a house which does not conform to the city code, but in fact represents an improvement over the code, the building inspector has a problem. He has no one to whom he can turn for expert advice; no one who can guarantee that the house will be safe if he approves the innovation. Furthermore, if he approves the house outside the code, and the house is sold, and the new owner has an accident traceable to the innovation, the inspec-

tor may be in trouble. This is a risk he is understandably reluctant to take, particularly since he has nothing to gain.

New building products also produce uncertainty for the buyer, and thereby create a problem for the vendor. A buyer may be intrigued by a new material, a new kind of window, or even a new kind of house, but unless he has codes or standards to go by he doesn't know whether it will do what it is supposed to do, or how long it will last. Promises are no help, for he has heard promises before. Not until the product has been on the market a long time will the cautious buyer feel confident that it is a safe buy.

This creates a really sticky problem. We need new materials, new components, new designs, new houses built by new methods, but cautious buyers make it difficult for the innovator to get his product accepted. It would be wonderful if we had a place where complete homes could be built, lived in, and evaluated by a neutral prestigious agency. It would reduce the uncertainty, and make life easier for the inventor, the builder, the inspector, and the customer.

Uncertainty is a hidden, but important factor in the high and rising cost of housing. I was quite intrigued with the experiences that Neil Mitchell had in Detroit when he had a chance to try out his system in a housing project, and found that the costs associated with the subcontractors bids were badly out of line. But we cannot blame the subcontractors, for they were being asked to quote a fixed price on unfamiliar installations. They had no experience to go on, so it would have been bad business for them if they had not made their estimates large enough to allow for a margin of error.

Something is badly out of kilter with our system of contracting for housing. Under the present system, oftentimes the architect is consulted after the land has been bought. He then proposes a structural design, we pay him, and turn his blueprints over to a contractor or builder and ask him to bid on the job. If his bid is near enough to the architect's estimate, we tell him to go ahead.

When the contractor first looks over the blueprints he may have some ideas as to how the building might be erected more economically, but he probably keeps his ideas to himself, for if he tells you about them, you will simply negotiate the price downward. We don't have a practical way to use the cleverness of the contractor to develop a cost-sharing technique whereby he and the owner can mutually benefit.

At the subcontractor level it is even worse. The various subcontractors may see several cost-reducing changes that could be made without reducing the beauty or value or sturdiness of the building; but they certainly are in no position to go over the contractor to the architect or the owner and suggest a different material or method of construction. As a matter of fact, the architect responsible for the design often may not see the house while it is being built, (some do, many do not) or afterward for that matter, so he never has a chance to profit from the lessons the subcontractors could teach him. As for the subcontractor, himself, the best thing he can do under this system is to do exactly what he is told, get through with the job as quickly as he can, and move on to the next one. All he gets is trouble if he plays the role of the fellow with new ideas who disrupts the job schedule.

It is the owner or the tenant who finally learns what is wrong with the building. The architect rarely learns; the builder may know but he isn't telling; the subcontractors mind their own business—so the same mistakes and the same wasteful practices tend to be repeated, and the opportunities for creative thinking and the development of cost-saving methods tend to be ignored.

The important thing is that, under this system, we can't blame anybody, for each man is doing his job the only way he can if he wants to make a living. We must find ways to change the building process so that it is to every man's advantage to do the total job better.

This is beginning to happen today. The concept of building teams is opening up new opportunities for cooperation among architects, engineers, contractors, city planners, and ordinary citizens, all working together and learning from experience.

This is one approach to getting the most out of the housing dollar. Good planning and intelligent cooperation lead to reduced costs and increased value.

But just increasing the efficiency of old methods is not enough. Two related approaches to industrialized housing offer the promise of great savings without the necessity for so much detailed planning for each individual project. I refer to prefabrication, and precoordination of modular components—or, as the Europeans prefer, "catalog building". The first refers to the preassembly of large components for onsite erection; the latter refers to the use of modular components which are dimensionally and functionally precoordinated for onsite assembly, permitting great flexibility of design.

Last year I had the opportunity to review with six builders from Europe their experiences with industrialized housing. I was particularly struck by the comments of Vladimir Cervenka of Czechoslovakia who told me about the housing program in his country. He concluded by saying: "But what you have to be careful of is monotony. I think that when the Americans finally decide to build industrialized housing they will show us all how to do it." He felt that modular precoordination was the most promising method for us.

I am interested in seeing the development of both approaches to industrialized housing, particularly since precoordination can play an important role in prefabrication. But it seems to me that for Americans, with our great love for individuality and variety, the use of a fully developed system for precoordinated modular components for onsite assembly is particularly attractive. If we can make every building lot a small-scale Willow Run—rapid assembly of buildings in a wide variety of styles from mass-produced, high-quality, precision-made, off-the-shelf components readily

available through local suppliers, we can bring to housing the technological miracle that has brought down the cost of such luxury items as television and the family car and made them basic parts of our living standard. And we can do it without paying the price of monotony.

Industrialized housing can benefit everybody. For the buyer, industrialized housing will mean better value at a cheaper price. For the builder it will mean less uncertainty as to costs, and a broader, more dependable market. For the labor force in the housing industry it will offer more stable year-round employment, and an opportunity to bring in large numbers of semiskilled and unskilled workers without unsettling the job market. If we add a million units of construction to the current annual rate—the minimum if we are to meet the Nation's needs—we will need these new workers to get the job done. We will still need all of the skilled craftsmen and professional men we can muster, but we will have thousands of jobs which can be filled by men with less skill and experience. This will go far toward providing a solution to the present tumoil in the labor force, and will tend to stabilize the entire industry. It will also tend to reduce tensions in our troubled society.

In recent discussions with people here in the Bureau of Standards, and with industry people, I have been pleased to discover that we have made and are making definite progress toward industrialized housing; in particular, that we are coming closer to the goal of precoordination. "Modular" is now considered a nice word by practically everybody; "dimensional coordination" is "in"; and "functional coordination" is just around the corner. And it is about time. We can't achieve the efficiency we need until we have modular components whose dimensions, tolerances, joining devices, and functions permit them to be coordinated rapidly and efficiently into a finished end product.

To sum up: To achieve our housing goals we need better management of the building process. This means large scale; and if we are to take full advantage of large scale we must utilize improved technology. If we utilize technology in an optimum way we must turn to industrialized building; and if we are to avoid the monotony of some early prefab construction we must develop a sophisticated system of off-the-shelf modular precoordination, whether assembly is completely onsite, or partially in the factory.

I think we can congratulate ourselves on the progress we have made toward this goal, but we should consider our present momentum as merely a running start for the big race which is yet to come—when the logjam breaks, and a national housing program begins to gain real momentum.

The economic and social indicators are flashing across the land. To me, they are signalling "URGENT! FULL SPEED AHEAD!" I hope I am right in sensing that this feeling of urgency is shared by the people who are active in this special committee of ANSI—A62 and that their actions will help to trigger a nationwide response to the housing need.

# Meaningful Interfacing, Key to Functional Coordination

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This presentation deals with the requirements of a dynamic building system of industrial components for meaningful subsystem interfaces. Meaningful functional component interfacing is critical for adaptation to changing use patterns and introduction of new, more desirable, systems. The need to relate functional components to anticipated mechanical or technical obsolescence is also a factor.

Key words: Dynamic building system; functional interface; technical obsolescence.

## 1. INTRODUCTION

The February 1969 Status Report of the A62 Standards Committee, which could be said to be the introductory statement for this conference, in its foreword said:

> The culture of the United States is dynamic with significant growth and changes occurring almost daily * * *. Buildings are constructed as static solutions to the requirements of a dynamic society.

The forword then proceeds to outline three possible strategies for coping with this dilemma.

(1) Replace static systems periodically to match change.
(2) Remodel static systems periodically.
(3) Develop dynamic systems that have inbuilt capacity to change.

It is this third strategy which is the subject of today's session. Yesterday's session concerned dimensional precoordination—today's is supposedly a new focus on functional precoordination. I submit that this is an artifical split. I believe that the core of functional precoordination is still dimensional. It is the implications of precoordination extended to include the fourth dimension—time.

Before elaborating on this point, it is necessary to explore trends in the current building process which appear as salient dynamic features.

Over the past 5 years I have had occasion to examine a number of building programs and to endeavor to breakdown the programs or the individual buildings into subsystems' costs, and, as far as the record will allow, to determine the ratio of subsystem implementation which stands on an onsite/offsite cost of operation. In 1965 we did some analysis on the military construction program and in the course of this, compared our analysis to comparable civilian buildings in the society at large. Figure 1 illustrates our findings. On the left, is a diagram referring to a three-story walk-up reinforced concrete frame barrack building, a fairly standard middle-of-the-range size building. Our data was taken from an analysis of the bids which were made by the Corps of Engineers. We grouped this data into the five major elements of the building. One was site operation; two was structure; three was the exterior envelope or cladding; four was interior components (finishes, partitions, doors, wall finishes, etc.); and, five was mechanical systems in which we grouped all the more dynamic service systems such as heating, ventilating, plumbing, electrical, etc. The salient feature derived from this analysis was that structure and exterior, (the major carcass of the building) accounted for only about 40 percent of total cost and this is with a building type (integral floor slabs and frame) where the frame is performing more than solely a major support function.

We had expected, at that time, to have these two elements account for a much higher proportion of the total building cost. On the basis of this, we went to other source material for other building types (shown in the bar charts on the right of fig. 1); offices, schools and apartments, hospitals, shopping centers, and dormitories. We found that this proportion of subsystem costs was relatively consistent in all types of contemporary building; i.e., that the dynamic mechanical support systems and interior fixtures and finishes, account for from 60 to 75 percent of the total construction cost of the building. As an extreme, one can see in the hospital that mechanical accounts for 50 percent, the interior elements or subsystems for another 20 percent-plus and that the structure and enclosure of the building, the basic carcass, is 25 to 30 percent of the initial construction costs of the facility.

We also took a look at the subsystems in relation to what percentage of cost was onsite as opposed to offsite. This is shown, in wedges of black and white, in the center circle of the diagram on the left of figure 1. One can see that there is no fundamentally different profile for any one subsystem over another. Our original thought was that mechanical subsystems would involve many industrialized components, resulting in a smaller amount for onsite costs, but in general the 40 to 50 percent split of onsite-offsite seemed to apply pretty much to every one of the major elements or subsystems of the building. The major conclusion we reached from this study was that in developing a comprehensive building system, there is little economic basis in the traditional fix in the industry on

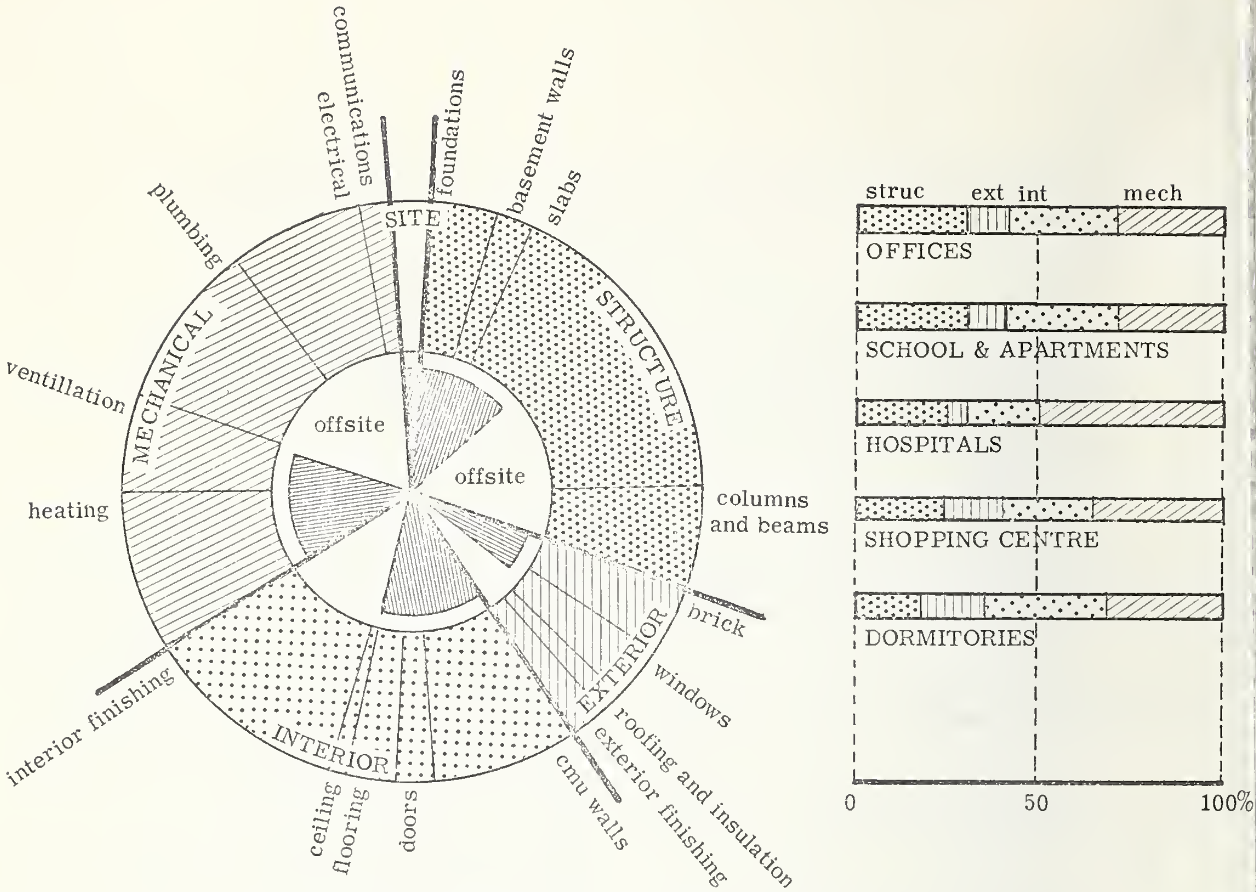


FIGURE 1.—*Cost Breakdown of buildings into major systems.*

structure and cladding (the frame and enclosure of the building) as the generator of the dimensional framework for the total building system. In fact, it appears that if one chooses to take as a basis for decision the amount of money involved in each of the subsystems, it is more logical to make the structure fit the optimum mechanical dimension.

Being surprised at the proportion of the dollar going into the mechanical system, we then looked to see how recent a phenomenon this was. The general picture of progression over the past few years is shown in figure 2. It was somewhat difficult to get data in this regard going back as far as we did, to 1925, but over these particular four types of buildings—hospitals, offices, dormitories, factories—we managed to find enough material to generate these particular curves. We can see that back in 1925, the mechanical systems were about 20 perecnt of the cost of construction of the building and these have grown steadily throughout the years, with remarkable consistency throughout different building types. There has not been a trend say, for hospitals to increase their proportionate cost of mechanical and other services and other types of buildings not to do so. The rates of increase appears constant implying an overall upgrading of performance requirements of each type of building. So, in 1965, the average for all types was around 30 to 35 percent and in the cases of some hospitals, it was more than half the total construction cost of the building.

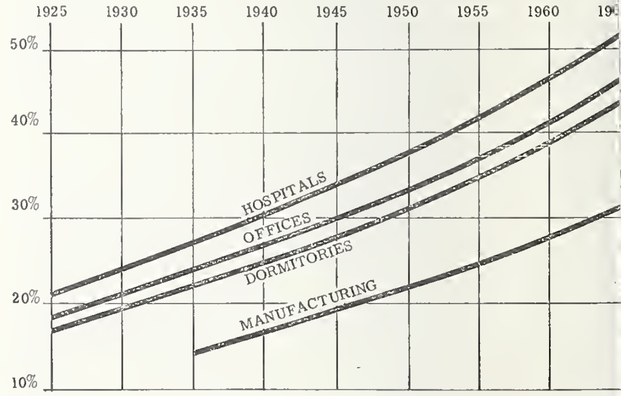


FIGURE 2.—*Percentage of total building cost for mechanical systems.*

## 2. INTERPRETATION OF TRENDS

One hesitates to project into the future on the basis of these curves (especially in relation to hospitals). However, this study does emphasize that current build-

ings, particularly within the United States, are more and more frequently becoming envelopes or armatures for dynamic environmental modulators and communications. A building is no longer a static carcass which is preset to perform a constant role, but has become a container for modulators of climate, environment, light, etc. These in themselves are dynamic, insofar as their intensity levels can be changed by the occupants or the stimuli of seasonal or diurnal variations, and in some measure by change in the function of the building.

It is useful, now, to examine these implications in more abstract or theoretical terms. In the past, when a building was designed, it was assumed that once it was finished there would be a static relationship between its parts to fulfill a function which would remain constant for the proposed life of the building. The site-based system of construction normally went on in a fixed sequence. Quite logically so. First the foundations, then the frame, then the closing in of the building, fitting of interior equipment, the addition of mechanical services, and finally the finishes. This constancy of sequence encourages a high degree of integration between subsystems. For example, it is an advantage to make loadbearing interior partitions that contain built-in duct-work, or which themselves form the chases or ducts for mechanical subsystems. The integration of different subsystems becomes such that their mutual boundary conditions (or interfaces) are no longer physically discernible (the loadbearing interior partition is both structure and duct, as well as interior subdivision) and it would not be possible to modify one without major rebuilding of the other. For this strategy, time is regarded as a constant. The construction sequence also becomes an integrated operation, so that as soon as the building carcass is placed, the nature and performance of service and other subsystems are immutably fixed.

A parallel attitude exists regarding the building use. In nearly every case, a building is designed to meet a program of spaces and functions which presumably will remain substantially unchanged throughout the life of the building. Therefore, performance requirements of the subsystems comprising the total building system will remain constant.

In these circumstances of "static systems" of construction and building use, the interfaces between component subsystems are not a critical area and the strategy of exploiting symbiotic interaction between subsystems that interface is the logical economical exploration of the initial premise of a constant relationship. But how valid is this strategy to meet future demands? Is the current construction process a technologically static phenomenon; and, are our current buildings being used exactly as they were planned? There is increasing use of prefabrication of components, and presite assembly of pieces (such as prehung doors or window wall sections), so that the site operation becomes more an assemblage of subsystem units than an actual fabrication. In terms of building use, increased individual and social mobility and the quickening pace of technological innovation now make user requirements a dynamic pattern that cannot be accurately projected over the normal life span of a building.

Given these changing circumstances, the overall system can no longer be regarded as static (unless its life is intended to be very short). With a dynamic system; i.e., one capable of adjustment, time must be regarded as an integral part of the system program. If time is a system variable in the construction and use of buildings then the interfaces between component subsystems are a most critical area.

Figure 3 is a diagram of the theoretical difference between the two strategies. The statically related system is the semilattice organization—subsystems and components are symbiotically interrelated—each capitalizes upon attributes of, and therefore, interrelates at many levels with, other subsystems. However, any adjustment of one subassembly will propagate a wave of adjustment through a large proportion of physically adjacent subassemblies and affect a high proportion of the whole system. The dynamic system is best exemplified by the tree—with the tree, the hierarchy is channeled. Each subsystem is absolute. The interface separation between subsystems is categorical and any adjustment of one subsystem will only affect others through adjustment of its larger system. (Of course, it is most unlikely that any building system would totally conform to either absolute—all will be combinations of both to varying degrees.)

One interesting digression is to acknowledge that borrowed this diagram from an article of a few years ago by Christopher Alexander called "A City is not a Tree" in which he explains that most urban planners, with the fix of an analytical discipline, tend to design new cities upon a tree organization basis. However, he suggests that the true essence of urban quality is the multiplicity and complexity of interrelationships between constituent parts of the city, of which the semilattice is the analogous diagram. It is perhaps a paradoxical hindsight, that this interdependence of the subsystems of our older cities is making it so difficult to update them to meet current demands, without making overwhelming commitments to major physical and political reorganization.

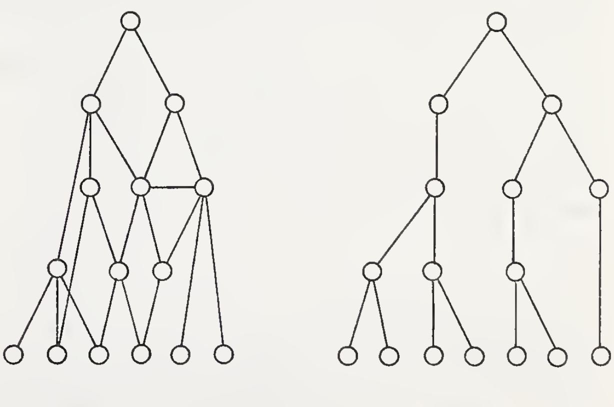


FIGURE 3.—*Diagrammatic systems organizations.*

## 3. ONSITE/OFFSITE FACTORS AT INTERFACES

In further examination of these interfaces of building systems, we focused on the onsite/offsite relationship of the subsystem. Figure 4 is an extension of figure 1. In figure 1 the major elements such as mechanical or structural appeared to have roughly the same degree of onsite as offsite proportion of cost. We were interested as to whether this was a basic consistency or a coincidence. We found that when we broke major systems down into subsystems, the proportion of onsite to offsite costs became remarkably different. For instance, take the HVAC system, grouped into three subsystem categories; one, the prime energy source, which in a heating system would be the furnace or boiler; two, the distribution system, the duct work or piping to move the modulating medium to the various places or spaces that it serves; and three, the local diffusion system, the subsystem at the terminal end of the distribution system, such as diffusers or radiators. Subsystem one, the mechanical room portion

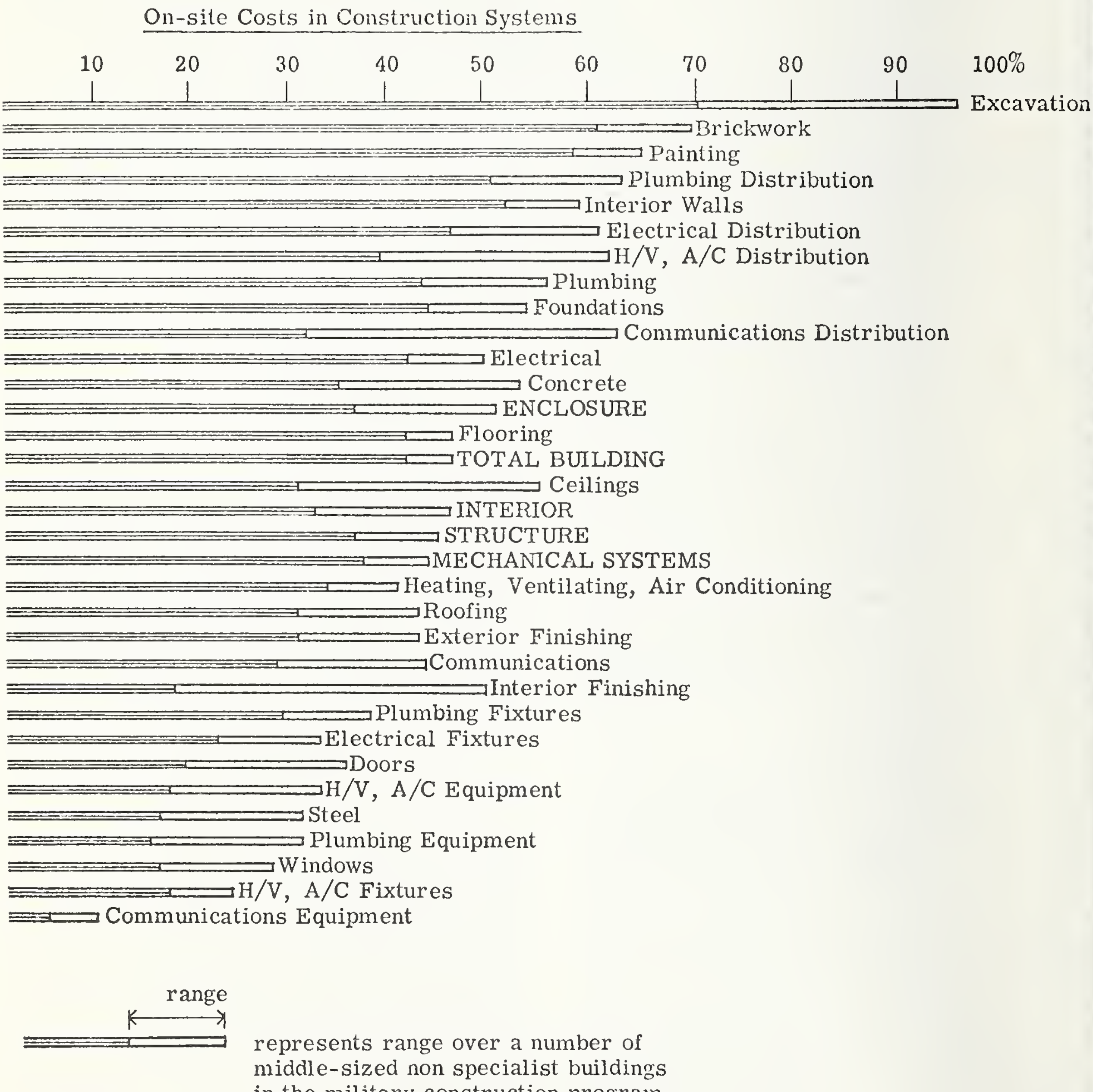


Figure 4.—*Proportion of onsite costs in subsystems.*

of the system, as one would expect, had a very low proportion of onsite labor while subsystem two, the distribution system, had a very high proportion of onsite labor. This is hardly startling. It seems very obvious that putting in all the ducting, at least in conventional construction methodology, is going to take a lot more time onsite than just installing the factory-produced furnace and connecting it. However, it led us to the insight that within one system there are many degrees of industrialization and, when one talked about a total mechanical system, it was a combination of subsystems of highly industrialized components and subsystems of lowly industrialized components where the bulk of the work was still being performed onsite. With the average HVAC system, about 35 to 42 percent of the total system is onsite cost and the other 60 percent is offsite. But with the distribution subsystem the percentage of onsite-offsite varies considerably from building to building, from 40 to 63 percent. We found that this was not so much a direct reflection of building function as it was a measure of the design strategy chosen for each building. We concluded that there had been little attention given by designers of this subsystem to the introduction of industrialized potential. There was an a priori conclusion that the distribution subsystem was so related to other systems of the building that it inevitably was a site-based operation with a concomitant high degree of site labor involvement. There is potential for savings in those areas which tend to occur at the interfaces between systems where the majority of site labor is applied, as we have seen in the installation of mechanical distribution systems, or in the application of the final finishes (fig. 4). Conversely, it can be said that the size of a system interface is a measure of the site labor involvement in the traditional building process. Site labor can be a major inflationary pressure on construction costs not only from the inflation in wage rates but also in the length of time that extensive site operations can add to the construction period during which capital investment is bringing in no revenue. Economic construction demands maximum efficiency and speed in site operations—hence the value of PERT/CPM to the scheduling of the building process.

## 4. SYSTEMATIC CLASSIFICATION OF THE BUILDING PROCESS

The analysis I have discussed so far has accepted the conventional construction process classification. We were interested in finding out whether this would still be the best departure for building systems capable of dynamic adjustment. We found that anything as complex and loosely integrated as the building process was susceptible to examination at many different criterion viewpoints, each of which tends to generate totally different subsystem classifications. Figure 5 illustrates this. The same building facility is at the center of all systems. An initial system classification can be generated from the point of view of user or task requirements. This results in subsystems related to environmental conditions, spaces, and equipment performing the task. This system would go to the procurement process as performance specifications. These specifications still need to be translated into construction elements. (The term "element" is meant to cover the range from individual building components or processes to assemblies.) In conventional circumstances these building elements are then translated visually in the CSI specification format into process specifications which derive from an analysis of the building process from a trade classification point of view, matching each element to masonry, millwork, and plumbing components. Trade grouping is the dominant system criterion in the industry today. It facilitates project administration but has little relevance to the actual functional goals. It permits easier contract administration through subbidding correlation but does not aid in dealing with production conflicts or appreciating performance requirements. (Note: most current data we have presented is in the format of trade groupings, not because this is necessarily the most relevant form, but because it was the form in which data was available.)

Finally, of course, the circle is closed by the interrelationship of goal and process. Process, or the trade grouping system, has effect through its political/economic constraints on the formulation of user requirements. A building program has the initial premise of discharging a task with the optimum efficiency but there is usually some tradeoff involved between task, economics, and politics in the formulation of the final building program.

Now, in what way will these different analytical systems be affected by the criterion of "Time"? We concluded that criteria based upon user needs and tasks orientation will be greatly augmented. However, each system variant will be affected by obsolescence. In each category, subsystems will become obsolete at differing rates and each system must accommodate some replacement long before the end of the life of the building.

## 5. TYPES OF OBSOLESCENCE

We classified five major types of obsolescence, every subsystem being sensitive to each one in differing degrees. The five, which are shown in figure 6, are the following:

1. Physical.
2. Performance.
3. Task.
4. Aesthetic.
5. Interface.

Physical obsolescence is the wearing out of components; their failure to continue performing according to specifications. This factor causes the bulk of building maintenance—replacement of worn out parts. Some of these components, such as fluorescent tubes, have highly articulated interfaces and are, therefore, replaced quite easily. Other areas of wear are wall and floor surfaces. Many are areas that the user is in immediate contact with, and thus are ones of which we are most aware. Physical obsolescence is also oc-

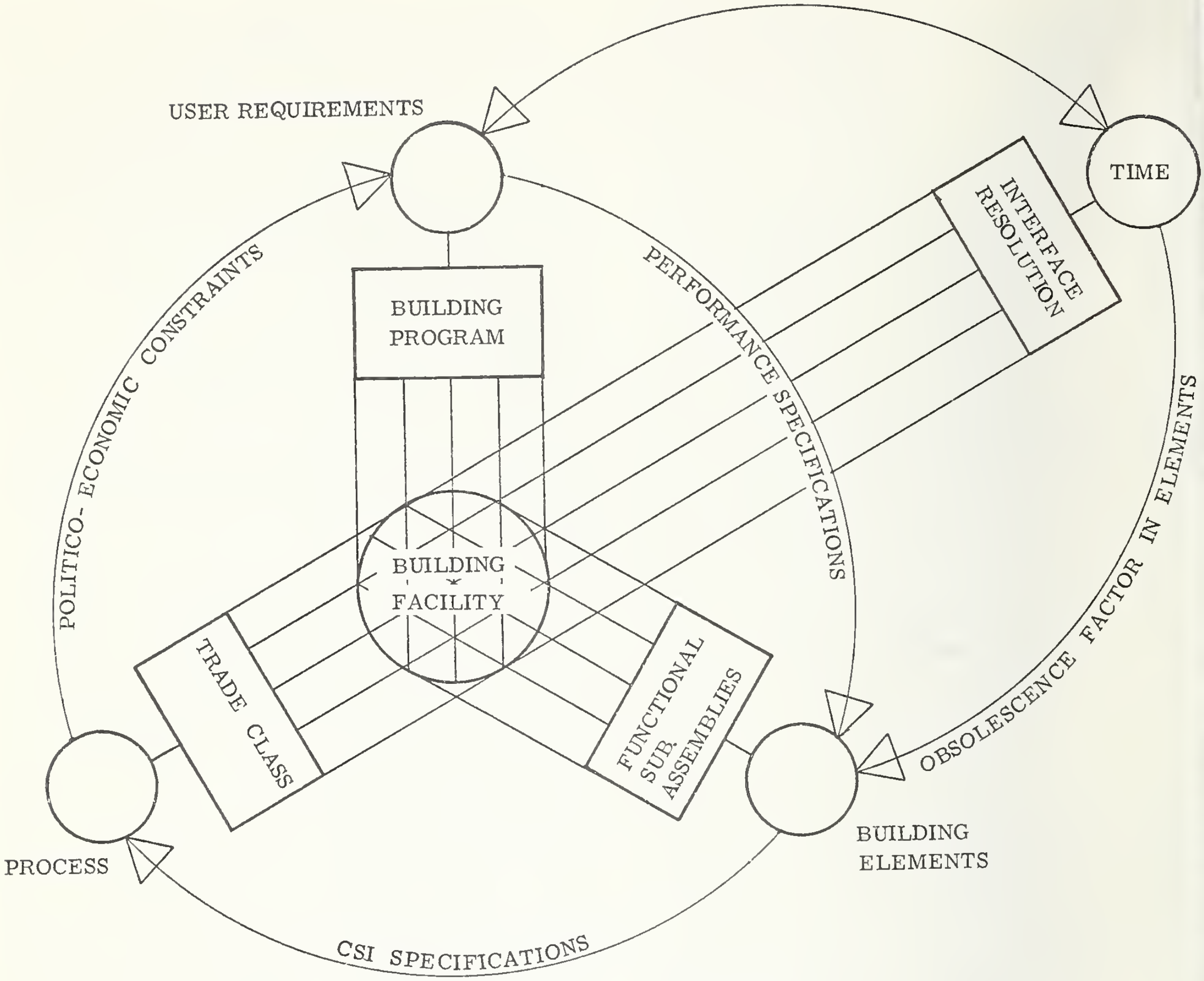


FIGURE 5.—*Diagram of the building process.*

curring within other components, some at a much slower pace. For example, a roofing membrance, if you are lucky, will last 20–30 years, though the life of the structure is much longer. We have not, in the past, tended to look upon our building as having the necessity to articulate very fundamentally in relation to these slower rates of physical obsolescence. Subsystems representing about one quarter the initial cost of the building will physically become obsolete within the normal 25-year lifetime of the system.

Performance obsolescence occurs when the standards and usage are upgraded so that the original system cannot perform to the level of the upgraded specification. This could simply mean higher user demands, as have developed for lighting intensity levels in office buildings. Or it might mean that new components have been evolved which perform the role much more economically, as when fluorescent light replaced incandescent for general illumination. Subsystems susceptible to this pressure amount to as much as 60 percent of the building costs.

Task obsolescence occurs when the role of the building or portions of it change—when the original function is surplanted, or else performed in a different manner requiring new conditions. An example is the recent growth of automatic data processing and the man/machine systems in which electrical equipment has replaced routine human tasks. This category is closely related to performance obsolescence, as can be seen in the introduction of man/machine systems. Usually both man and machine require a higher service level than before. Although most subsystems are liable to task obsolescence, probably those most vulnerable are identical with the list already compiled for performance obsolescence.

Physical performance and task obsolescence are usually countered by servicing of buildings after initial completion—maintenance, modernization, and remodeling are common terms covering these servicing activities. In any dynamic system, the building facility cost must be appraised as the total cost over the facility's entire operating life. Current fiscal practices tend

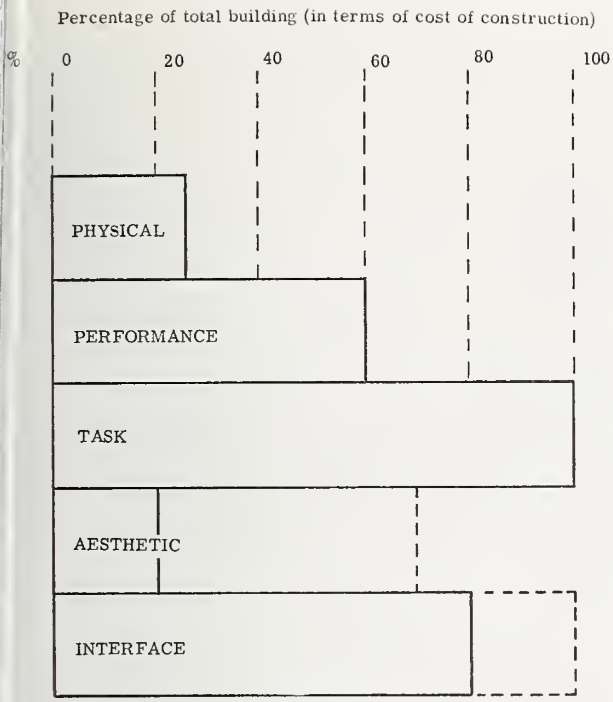


FIGURE 6.—*Types of obsolescence.*

to minimize this approach but any large, long range facilities usage program by such entities as metropolitan school boards, large corporations or government departments should give greater weight to these factors in their initial programing. Figure 7 illustrates this point. It shows the U.S. Military Construction Program over a 10-year span. During this period, the total inventory (sq. ft.) remained relatively constant. During this same period, new construction, maintenance, and rehabilitation continued at fluctuating rates. Though apparently separate programs under separate control, both programs were concerned with the redisposition of the same total amount of inventory. The whole military construction program over the period could be classified as part of the same mechanism of countering obsolescence, apparently new construction being the mechanism of task obsolescence, replacement, and maintenance covering physical and performance obsolescence.

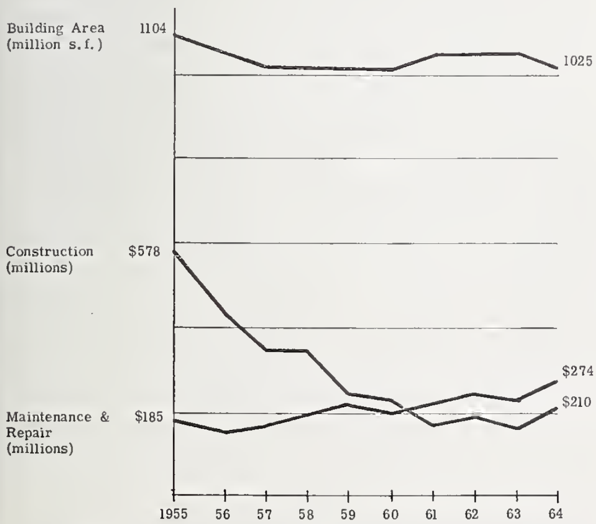


FIGURE 7.—*Pattern of Army construction program.*

Aesthetic obsolescence results from changes in user attitudes, which in turn result from shifts in societal dynamics or stylistic cycles. This obsolescence is most readily discernible at its broadest manifestation in commercial buildings, where store fronts, for example, are continually being "updated." However, this factor will become increasingly important in an affluent society where there is competition among all sectors of the economy to attract staff or prestige through emphasis on the "image" or qualitative aspects of the environment. In narrower and less subjective terms, aesthetic obsolescence dictates the frequency of surface refurbishing, replacement of plumbing fixtures and other furnishings, floors, etc., usually much prior to their need for renewal because of physical obsolescence. Since aesthetic obsolescence is always manifest through the subsystem/user inteface, those portions of subsystems which are exposed to view are usually most sensitive to this pressure.

Although subsystems which have this user interface aggregate 70 percent of the total cost of the building, it is only about one quarter of each subsystem which is directly affected. Therefore, it is probably safe to say that 20 percent of the initial building investment is susceptible to localized aesthetic obsolescence.

Finally, interface obsolescence occurs when one system becomes obsolete and, because of interface integration, cannot be divorced from an adjacent subsystem which is still operative. Hence, both subsystems are scrapped—the second for interface obsolescence. Other economic factors frequently influence the degree to which interface obsolescence will operate. For example, the performance life for a building structure is 100 years plus. When most of the other subsystems are obsolete, it is the usual course to scrap the whole building system, the structure thus disappears as a result of interface obsolescence. However, in some recent mid-Manhatten instances in the highest ground rent areas, significant time and hence money saving has been realized by stripping down the whole building to the exposed structural steel and preserving this one (nonobsolete) subsystem for incorporation into a new building system.

The largest scale manifestation of interface obsolescence occurs when a city area or other site environment becomes obsolete—such as in an urban renewal situation. Then because of an "inarticulatable" interface—the mobility to move—a whole building facility can become obsolete from interface obsolescence. The interface in question being that of the total building with its site or environment.

## 6. CONCLUSIONS

The preceding has been an exploratory analysis rather free in hypotheses and assumptions and hence tentative in conclusions about the development and future implementation of industrialized dynamic building systems. First, we can conclude that user requirement criteria and building programs must show less fixation on the methods and cost of initial implementation and take a much longer range view as to assessing the efficiency of building elements to absorb factors of obsolescence. Current tax structure and fiscal climate tends to divorce operative and maintenance costs from capital investments and thus obscure comprehensive analysis of the total cost of a building facility. For organizations responsible for long-term operation of a large building inventory—national corporations, government agencies, etc.—countering obsolescence should be an increasingly important planning factor.

Future systems should include criteria relative to the usage of buildings in addition to those relative to initial construction. The cost of a construction program does not cease with the construction of the building; neither should system criteria. There is need for further data on the usage pattern of buildings, especially relative to their initial purpose and effectiveness of the primary investment. Our figures show that rehabilitation and other building maintenance costs are significant. They should be more realistically reflected in the criteria for building design and procurement.

## 7. GENERAL STRATEGIES FOR DYNAMIC BUILDING SYSTEMS

The three possible implementation strategies which I earlier quoted from the foreword of the A62 Status report are worth reexamination. Although the foreword opts for the third alternative-dynamic systems as the most valid, we ought not discard the others without more scrutiny.

Strategy 1.—Expendable facilities—implies a low initial cost and rapid obsolescence of the total system, and its replacement by the next generation of improved and/or modified versions. To implement this, buildings would become industrial products with high autonomy and hence minimum environmental interface. Building would become a program of rapid turnover of what we now tend to regard as temporary buildings.

Strategy 2.—Remodeling will not succeed if we view it in the expediency of what we do with the existing inventory which we can't quite bring ourselves to throw away. The rehabilitation housing program in older cities shows that this is too formidable a task. However, if we update our concept of remodeling to be that of new facilities that have a relatively fixed character of overall system, which has capacity for adjustment through differential subsystem manipulation, then we achieve some dynamic capacity which can be easily integrated with current building philosophy, as it permits the building system to appear to remain unchanged while the subsystems undergo their smaller scale transformations. This strategy also can be accomplished with the current trade-oriented system of the industry.

Strategy 3.—Major dynamic capability implies a variable overall system made up of ad hoc combinations of autonomous units of integrated subsystems. The integrated subsystems can then exploit symbiotic interfaces. In other words, the building facility becomes an assembly of separate task modules. This assembly would be dynamic, insofar as changes in function are met by altering the nature of the assembly, but each task module in itself is a static system. Thus classroom task modules with other kinds of basic task elements can aggregate into a school. However, the school system is dynamic in that classrooms can be attached or detached from the main service system or even replaced in updated types of facilities—say with many increased audiovisual instruction facilities.

I think, finally, I ought to say that I don't think any building facility in the future is going to fall categorically into any one of the classifications that I have given here. All facilities will be a combination of both tree and semilattice system relationships and will perform efficiently as such. Of course, some will tend to be more one than the other; those that require dynamic readjustment must be more tree than the average building is right now, although obviously a lot of the subsystem components will fall into a sort of semilattice relationship in regard to their local function. I think that the other major conclusion (which is not all that new, but is worth reiterating) is the role of mechanical and other dynamic service systems in current building. They are now indisputably the major subsystems of any building facility both in initial cost and in operating cost and I think that, for any approach to give dynamic capability to our buildings in the future, we must make this our major point of departure rather than the older conventional ones of structure and enclosures.

# Precoordination Needs in Component Design

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From the manufacturers' standpoint, it will be necessary to identify the various types that will be responsive to systems design and establish performance standards for each. These performance standards should include operational performance standards, operational costs standards, and maintenance standards. After building types are identified and performance standards are determined, it will then be necessary to consolidate as far as possible the elements that can be used in a number of different building types.

The requirements of flexibility must be rationalized and a modular dimension for horizontal planning and vertical planning developed. Finally, a standard performance testing must be developed to enable all sectors of industry to respond in a satisfactory manner to the component design requirements.

Key words: Component design; flexibility; modular dimension; performance standards; rationalization.

I will attempt to develop a case study of one component area—namely heating, ventilating, and air conditioning—and develop the precoordination needs for this one component.

Before I begin this discussion, however, I would like to comment on certain terms that have been used during this conference. Terms such as standardization, precoordination, integrated systems, compatibility, interface, open system, closed system, comprehensive body of coordination guidelines, dimensional compatibility, and interchangeability, plus many more have been used to some extent in virtually all of the talks; however, we have never really defined these terms and I feel that this is the crux of one of the problems in dealing with system programs. I will attempt to address myself to you in lay terms and until such time as some of the terminology has been clarified, I will attempt to avoid this element of confusion.

I can only speak about the degree of standardization within one company, namely the company I represent; however, we have a certain amount of standardization that has developed as the result of purchasing, inventory, and service requirements. Within the framwork of a given capacity range for heating and cooling, many of the following items have been standardized: blower wheel size, blower shaft, blower shaft diameters, bearings, fan belts, safety controls, operating controls, cooling coil design, compressors, and so forth. Also, within one company, the product engineering data or software, as it is known, carries a standard format which applies across a complete product line. While there are other areas where some degree of standardization has been attempted, we find that we have a very serious lack of standardization when comparing the products of one company to those of another.

An effort to standardize performance has been made by several agencies; namely the American Refrigeration Institute which has a standard method of rating cooling equipment and also is actively involved in establishing ratings for sound level. The American Gas Association has a standard method of rating and testing gas-fired heating devices. Also, the Underwriter's Laboratory has standards for testing and rating electrical components, wiring, etc. The main emphasis of the Underwriter's Laboratory is on fire prevention and safety. The Canadian Standards Association also works in close consort with the Underwriter's Laboratory; therefore, we are arriving at a degree of standardization across foreign boundaries. The National Association of Roofing Contractors has developed standards for mounting frames for mechanical units which are located on the roof. The purpose of this standard is to permit the bonding of a roof for an extended period of time.

One of the major problems with the standards established by the agencies mentioned previously is that these standards are not acceptable in all localities. An example is the American Gas requirements that are amended by a national code that does not accept zero clearance. The American Gas Association does have a zero clearance rating for a product, which means that a heating device can be set directly against a combustible material, but one of the national codes will not accept this zero clearance. Also Underwriter's Laboratory requirements are exceeded by those of local agencies regarding borrowing practices in both California and the Northwestern States of the United States. A uniform standard acceptable in all 50 States would substantially reduce the cost of the manufactured products.

An examination of the current procedures used in the heating, ventilating, and air-conditioning industry regarding the method in which products are specified, indicates that almost all specifications are written around a material specification. The use of the material specification has produced virtually a zero level of standardization. The relationship of the mechanical

unit to the rest of the structure had to be worked out individually for each job. In other words, we have been forced to reinvent the wheel on every project. The basic results of this have been more onsite labor, a lower level of quality, longer construction time—all of which add up to a higher cost.

If the use of material specifications has not been totally satisfactory, what are the alternatives? Would the use of a performance specification help in the role of standardization? Personally, I believe this procedure would result in a higher level of standardization. By looking at operational performance, we could specify a temperature range to be maintained within any structure of plus or minus a certain number of thermal degrees. The humidity levels can be stated to maintain plus or minus a given percent, as well as the filtration levels and sound levels. In talking about sound, we must consider both the inside sound levels and the sound level outside the structure which is created by equipment located outside. An example of a problem that occurred when this was attempted a few years ago arose in Florida. A local requirement in Florida specified a certain db level on outside condensing units. Actual tests showed that the night sounds including the chirping of crickets exceeded the local code of maximum sound level. To me, this indicates that much serious professional thought and evaluation must go into the establishment of performance requirements. The performance requirements of the structural envelope bear a very positive relationship to the thermal environment created within the structure. If uninsulated walls or large expanse of glass will create cold surfaces, then we have a potential problem of radiating heat from the human occupant to the cold surface. This certainly will change the thermal requirements and effect change in the entire mechanical system.

Standards can be developed relative to the allocation of space for mechanical equipment. One possibility might be on a unit capacity of a maximum number of square feet per 10,000 B.t.u. of heating capacity; or a maximum number of square feet per ton of cooling. To arrive at this standard level, there must be an evaluation on the basis of the cost per square foot for the mechanical unit against the cost of the manufactured unit. This is nothing other than an economic study to determine if reducing the size of a mechanical unit will save enough floor space to support any additional cost this size reduction may evolve. On rooftop equipment, some standard of weight of the mechanical equipment per square foot of roof area would allow a standardization of the structural system.

Another area of standardization could be in the cost of operation. A minimum allowable B.t.u. of cooling per watt of power consumed might be one approach. The U.S. Post Office Department has been working with this discipline.

The cubic feet of air delivered per minute per blower horsepower at a given static pressure would be yet another standard. As an example, an air distribution system designed on 4 or 5 inches of static pressure will require roughly three times the blower horsepower required for a low velocity, low pressure system of 1 inch of static pressure.

Maintenance cost standards would be extremely valuable to the building operator. A maintenance cost schedule for a mechanical unit on the basis of a given number of dollars per year per 100,000 B.t.u. of heating would allow the building operator to project his maintenance costs. This could also be applied on a given number of dollars per year per ton of cooling. This sort of a standard must be related to degree-days to adjust for geographical differences. Also, these standards must be adjustable by the escalation index of labor and materials. This area appears to be an excellent challenge for the computer which can handle the variables, provided an intelligent program is written for the computer.

The above standards that we have been discussing must all be related to a specific building type. As an example, to state that a standard is developed for the educational market indicates, in effect, too broad a standard. The differences between the elementary, secondary, junior college, and college and university requirements will produce some degree of separation of standards. Within the housing industry, we have single-family detached housing units, row housing or townhouses, low- to medium- and high-rise apartments. In each of these categories, standards for mechanical systems could be developed, but again, they should be separated by the individual category of housing. We could continue on with hospitals, differentiating between nursing homes, small to 100-bed hospitals, and large hospitals; along with offices, shopping centers, etc.

Perhaps one of the most significant effects on standardization has been the development of building systems. I'd like to quote from Mr. John R. Kubask, who wrote in Contractor's News, July 1969 the following statements "If the system concept is to get off the ground, there must be standardization to achieve volume." Looking at the most basic segment of the building industry, the single-family detached dwelling, Professor Albert G. H. Dietz, Professor of Building Engineering at MIT, at the summer seminar on industrialized building held August 18 through August 29, 1969, made the following statement: "In connection with the study of the component construction in single-family detached dwellings, various modular sizes of wall and partition elements were compared with respect to flexibility of arrangements and costs. The conclusion reached was that many combinations were about equally acceptable and that the module should be based, not on structural requirements, but first upon the most efficient use of dimensions dictated by the heating, plumbing, and kitchen equipment; and second, best panel sizes for windows and doors. Plain structural panels could be virtually any modular size that met the first two criteria. If these modular requirements were met, great flexibility in arrangement could result. That is, many efficient unstandardized plans could result from a small number of standard components." From the preceding statement, it becomes obvious that any success in standardizing HVAC ele-

ments must be related to all adjacent and related subsystems. One of the type B proposals for "Operation Breakthrough" deals with manufacturers of plumbing components, another with manufacturers of heating, ventilating, and air-conditioning units, a third with manufacturers of kitchen appliances and cabinets, and a fourth with manufacturers of polyvinyl chloride piping for waste and supply systems. These four manufacturers are coordinating their products into a Heart Module to get the utmost value and benefit from the efficient relationship of these elements. These elements represent from 25 to 30 percent of the cost of a residential living unit; therefore, it represents a sufficient number of dollars to concentrate on an attempt to get a major reduction in cost.

An examination of the standardization of some of the elements of building systems might serve as an example of the points that I am attempting to bring out. The School Construction System Development project in California employed a heating, ventilating, and air-conditioning system that had four basic duct dimensions for 600 to 1,000 cubic feet of air per minute. There were four additional duct sizes for 1,500 to 5,000 cubic feet of air per minute and there were only three different duct fittings used. This was on schools that ranged from 20,000 to 270,000 square feet. Further, a complete duct layout which was standard could be used on a repetitive basis. There were 12 such layouts developed for specific areas such as the academic spaces, administrative spaces, science areas, industrial arts, gymnasium multipurpose use, food service, and exhaust air systems. In the SEF project in Toronto, Canada, there was one basic duct size which was a 10-inch round duct. This was accomplished primarily because the performance specifications spelled out the need for 450 square feet to serve as one control zone. In Montreal, in the RAS project, there were three sizes of ductwork used. A 10- by 7½-inch duct made up 15 percent of the total ductwork, while a 14- by 7½-inch duct made up 70 percent of the ductwork and an 18- by 7½-inch duct made up the balance 15 percent.

It was estimated that a cost savings of 20 to 25 cents per square foot of building area was achieved by standardizing ducts. This can be a rather significant figure when you assume that 10 to 12 percent of the entire cost of the job amounted to heating, ventilating, and air-conditioning equipment.

The American National Standards Institute Standards Committee—A62 has spelled out in its A62.21 section that the allocation to mechanical systems in floor-ceiling systems should be one of the major developments. By following up on this section, it is possible to develop space allocations for various mechanical requirements within the floor-to-ceiling sandwich. The opening in structural members becomes a very important part of standardization programs. Programed openings in concrete members become necessary when developing a two-way duct distribution system through the structure.

The basic size of the mechanical units should adhere to some level of standardization, particularly when we relate the product to an over-the-highway shipment. In most States there is a maximum width of a product to be shipped over the highway without special permits and special escorts. By designing equipment to be within this standard width, many of the shipping problems are minimized. In the instance of my own company, we have developed special trucks and trailers and also specially equipped railcars to transport a major rooftop product from the point of manufacture to the jobsite. This becomes an essential part of the system design and also bears a close relationship to the subject we are discussing today and that is standardization.

In conclusion, from the preceding comments there does appear to be a degree of standardization in the heating, ventilating, and air-conditioning industry. However, the A62 Committee can develop a much higher level of standardization and they are working toward that end. Our industry must also respond to the need of standardization if meaningful progress is to be accomplished. The future of building systems is linked closely with standardization. The need for increased volume of buildings has now outpaced our ability as an industry to construct this required volume. System design and system building can meet this need with proper response from industry, the design profession, and labor, and also assistance from the Federal government in aggregating land and influencing change in zoning requirements and codes. Organizations such as the National Bureau of Standards and the A62 Committee have made significant contributions and I am confident that they will continue to do so in the future.

# Precoordination Needs in Building Design

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This presentation explores the types and content of functional and dimensional standards that would be required for the design of buildings without relating that design to particular products or proprietary solutions; in other words, that dimensional and performance standardization which is essential to eliminate custom modification of part or building design on an individual building basis.

Key words: Dimensional standards; functional standards; precoordination.

About 4 months ago when I was invited to give this talk I should have written it down, then I would have been able to tell the Bureau what I was going to say. If I had done that, it would have been a very different and perhaps a very factual talk. I wrote down what I am going to say 3 days ago after going through two paralleled submissions to HUD's Operation Breakthrough. The effect on me of Operation Breakthrough will perhaps make itself felt in the next hour. My problem is not to talk for an hour but to keep from talking for 2 days.

You may wonder how, I, an Englishman, a Canadian resident, a professional quantity surveyor, a builder, among other things, come to be speaking about this subject here in Washington. I am here because I was invited; perhaps because I have suffered from the lack of precoordination and I have not suffered in silence.

I have over the past few years been closely associated with building systems and their integration. One was not really a system and it had a lot of integration problems. One was a complete system and all the integration was solved on paper before anything was built. One was a more complete approach and is a HUD submission, showing how most of the interface problems can be solved. One was a multisystem again for Operation Breakthrough. There have been others not so successful.

I want to refer to the scope of the A62 Standards Committee and in particular to the few words in that scope which say: "so that they integrate with the minimum of onsite modification." This is how I see my talk today—to discuss those few words. We are striving for the minimum of onsite modification which seems to relate to the maximum of offsite prefabrication.

My brief for this talk said that I could explore the many facets of understanding that must be worked out between a client and manufacturers in a performance based project. I can't do that—not in those words.

I think that the A62 Standards Committee exists to lay down a dogma in this matter—to create a creed that we may follow in systems building.

There will be those few who will question the dogma, and in a healthy society, those few should always be vociferous and should always be heard; but for most of us, we will be glad to have the rules of our faith defined for us.

Our aim is not to make all our buildings like figure 1; an aim which betrays a goodly amount of systems thinking. But following the rules, to do a little better than figure 2 which has none of the systems thinking. I always relate components to the common building brick (fig. 3). The brick has volume, proportions, length, width, and height; it has joints and it can be placed side by side or stacked to make pleasing patterns (fig. 4) and as the picture shows, it can be carried attractively: It is eminently portable and very popular. The brick is perhaps the earliest attempt at a building system. One can imagine how the inventor of the brick was received (fig. 5). He was probably stoned by the wattle and daub merchants who said "what was good enough for grandfather is good enough for us." The brickmakers persisted and are with us today. They in their turn have not progressed very much except that they now know how to make bricks faster and with much closer tolerances than before.

Figure 1

Figure 2

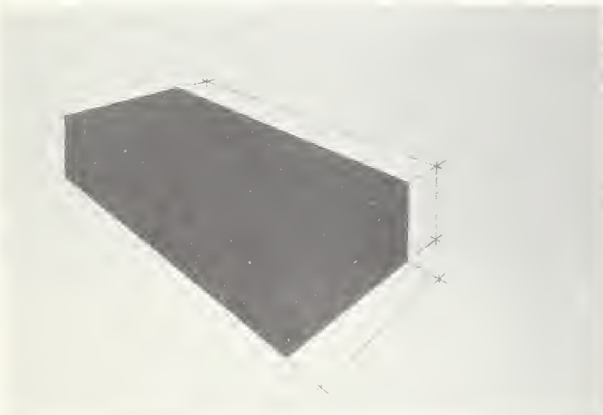

Figure 3

But there are some among us who seeing the opportunity presented by our progression from the transport of past ages (fig. 6) to that of modern days (fig. 7) have seized the opportunity to make bigger bricks (fig. 8). This is a view of a systems building volume occupied by a structure consisting of transportable frames and a slab. Typically 20 feet wide × 13 feet 4 inches high and 20, 30, 40, 60, or 80 feet long. It can have varying height and varying widths. It is to systems building a very big brick.

Figure 9 is a picture of another large systems building brick. One thing is common to the brick and the large systems component—they both have joints—they both have interface conditions.

Figure 10 is obviously a stack of bricks separated from one another in all directions by joints. One of the bricks has been removed to show its manufactured size and the position of the interface.

Figure 4

The large systems components can be stacked too (fig. 11). Here are several of the volumes produced by the component arranged in a regular manner, side by side, and one atop the other.

It is in recognizing the joint, the interface, that the skill of the systems designer becomes apparent. Even today, a great deal of time is spent on deciding what is the joint, where does the component end and where does the next component start. There is only one logical place for the component to end and the A62 Standards Committee must define it. I know where I think it should be. It should be basically on a gridline of a modular system (fig. 12). It does not matter how large or how small the grid is; or how many grid spaces the component covers, it must end on a gridline. And, because it has an interface, a joint, it will probably end in fact a little way from the gridline.

There is another word to remember here and that is gap. The gap is the distance between the interface plane and the edge or side of the component. The gap is important and is nearly but not exactly half of a joint. The gap is very important when it occurs at the outer edge of a system. It is there but it can't be seen.

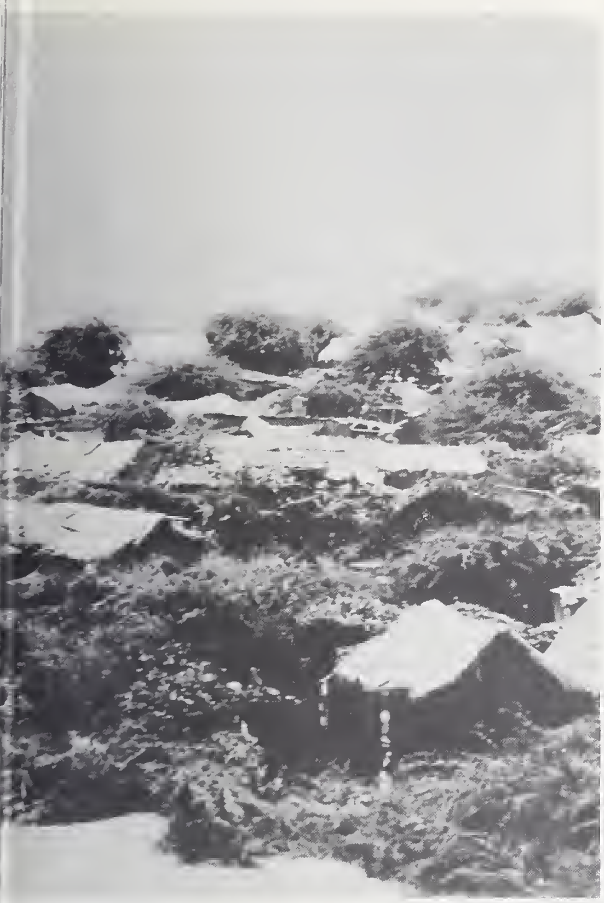

Figure 5

Figure 6

It is important to the geometry. The slide shows how the movement away from the gridlines takes place in a regular geometric manner.

I used the word "basically" and I am defining one of the things a designer must know or be able to determine from the specification: the "basic" dimension. This is a measurement of one or more modules into which the component will fit without making adjustment of the surrounding components (fig. 13).

The gap must be defined and very carefully defined since it must take up the space between the edge of the component and the gridline and it often must be filled with something—a gap closer, a mastic joint, a cover bead, a piece of trim, or it may be just space. From the definition of the gap, the designer can find the maximum dimension of the component.

Looking again at the big systems brick (fig. 14), we can see that its maximum dimension can be nearly 20, 30, 40, 60, or 80 feet long. In every case, it is nearly that length by the distance of two gaps. Those gaps are important.

A lot of things affect the size of a component and the designer must be thoroughly familar with the manufacturing process and the temperature changes which can occur causing change in length of the material (fig. 15).

Taken all together, these are refererd to as tolerance and the total tolerance will reduce the maximum size to the minimum size and the gap will become larger. It now becomes a gap plus half the tolerance. In a well-regulated system under perfect conditions, two gaps plus the tolerance equals the joint.

And the specification to the designer must describe what this should be, since perhaps the only way he has of limiting the joint width is by making more components if a close tolerance cannot be kept.

This is not all that the designer must consider. He must know how accurately the component can be placed in the building and another tolerance creeps in. This may be plus or minus to the joint and the final point of definition is "What is the smallest gap and what is the largest gap that is acceptable?"

This type of specification is not really new, considering this building and the exacting definition of interface which was required so that the intricate geometry could be laid out (fig. 16). Or this screen (fig. 17). Here it is in close up (fig. 18).

Notice the regular geometry of a systematic approach and liken it to what we are trying to do today (fig. 19). If this rule were followed exactly, there would be no custom modification.

There are other things which the designer needs to

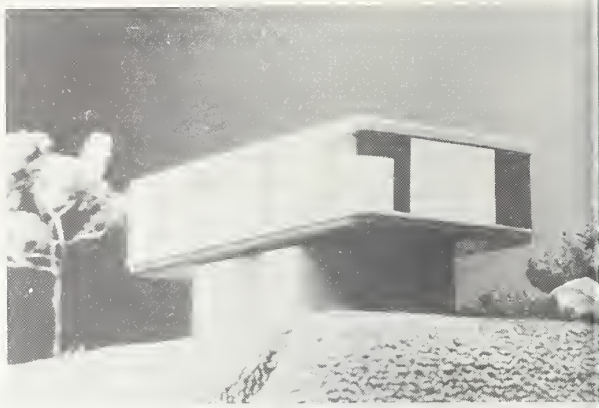

Figure 9

Figure 7

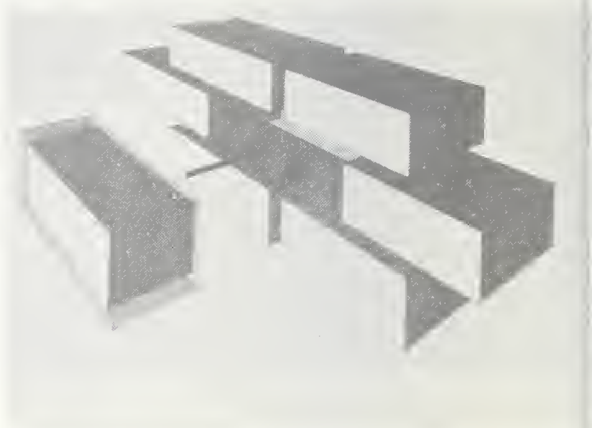

Figure 10

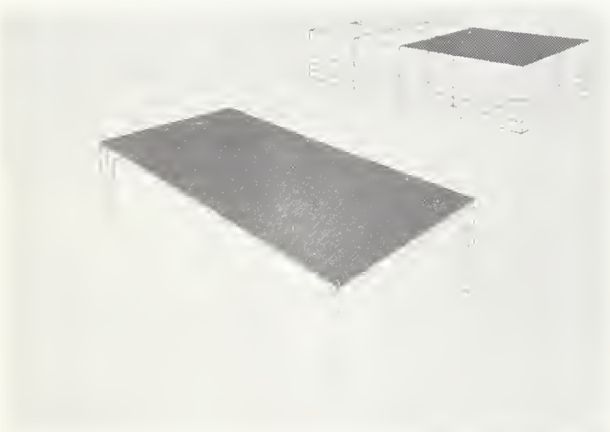

Figure 8

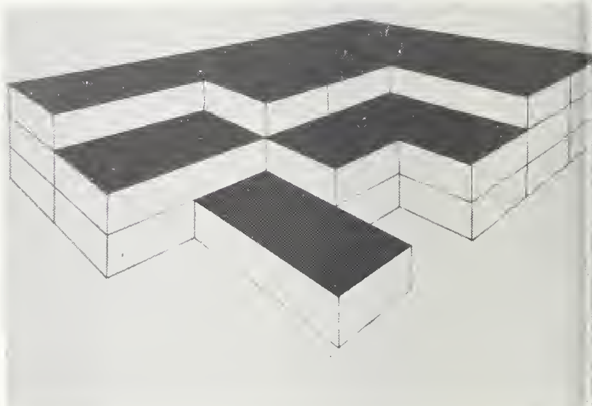

Figure 11

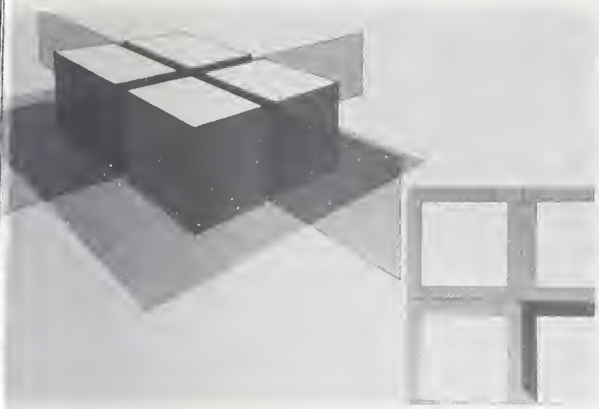

Figure 12

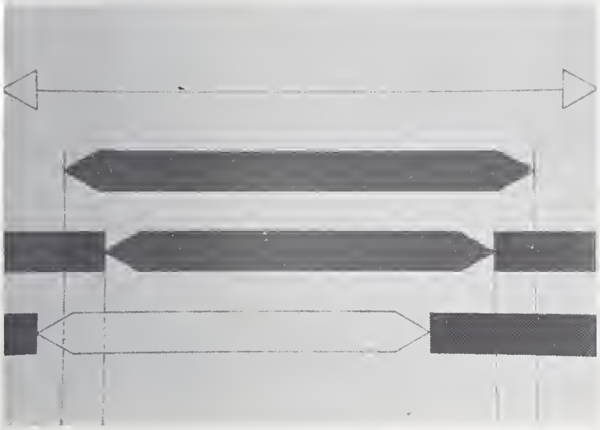

Figure 13

Figure 14

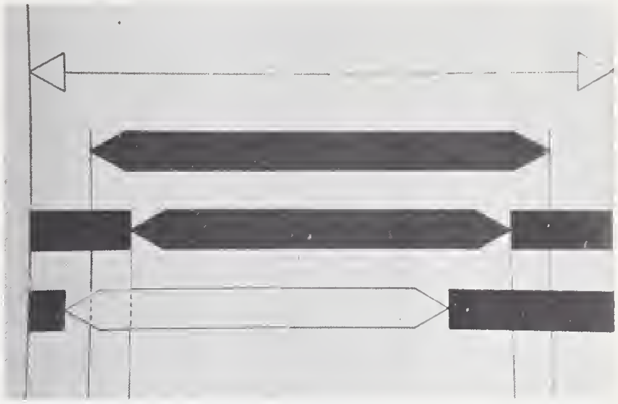

Figure 15

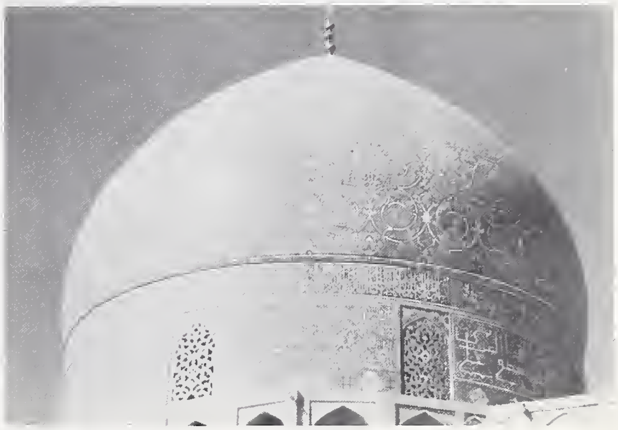

Figure 16

know such as the strength of the component, its resistance to weather, abrasion, inpact, its sound transmission and heat loss capacities. And then, he must study the interface. What is that joint, what is its material? If it is a joint between two of the same kind of components it may be simple, but it may be complex like the joint in a precast concrete rain-screen panel. If it is a joint between different components, then an exact specification of the behavior and position on both sides of the joint is needed. This is the point at which systems coordination often fails. Who is to define the joint? How was the joint defined here (fig. 20 and 21) or here (fig. 22)? May I suggest that our joints are relatively easier (fig. 23).

What happens when two materials with very different joint requirements come together? May I suggest that the joint becomes a component? Or part of one of the others?

The latter is preferable and the rule much easier to apply. From the overall specification point of view that is. From the individual component manufacturer, there may be some complaint. Recent experience in the R.A.S. schools project in Montreal where this kind of

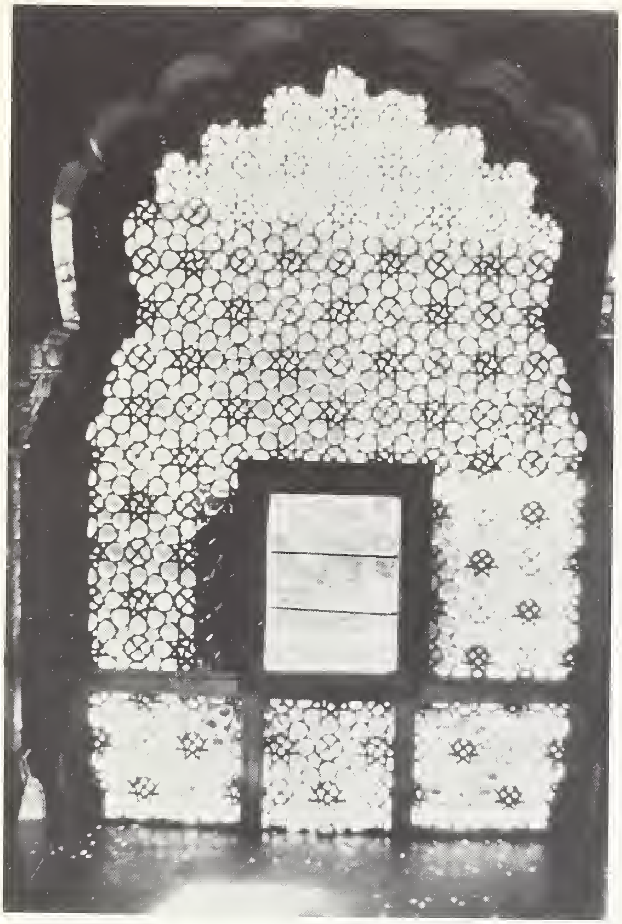

Figure 17

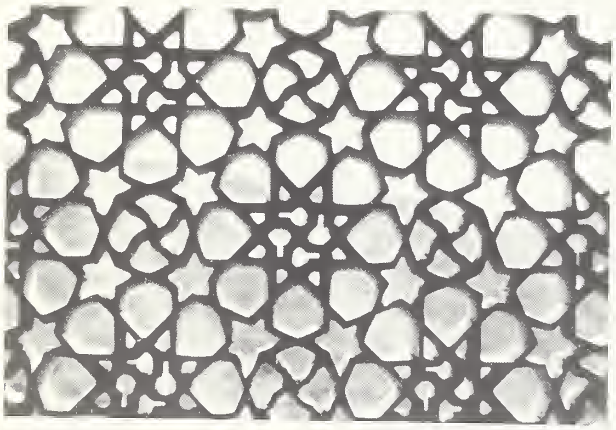

Figure 18

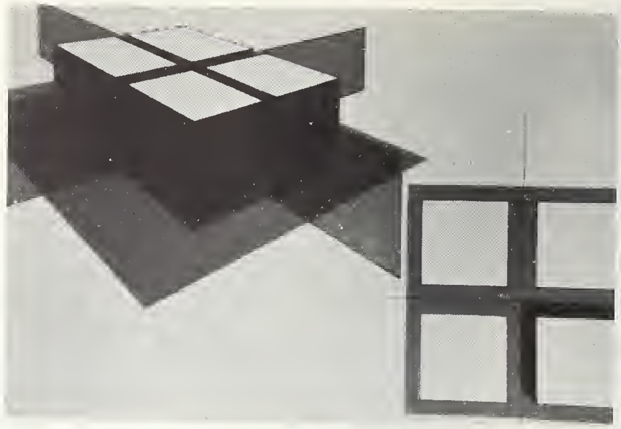

Figure 19

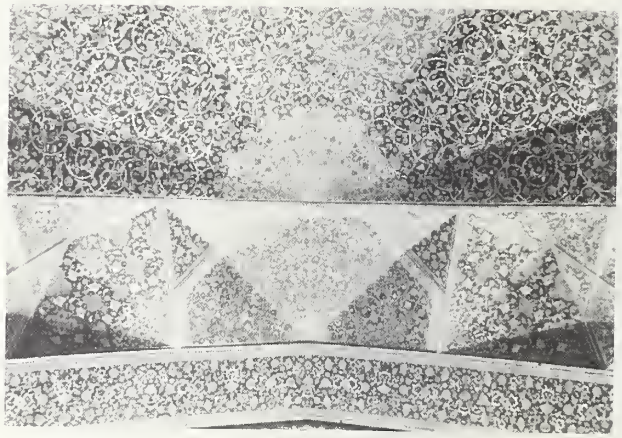

Figure 20

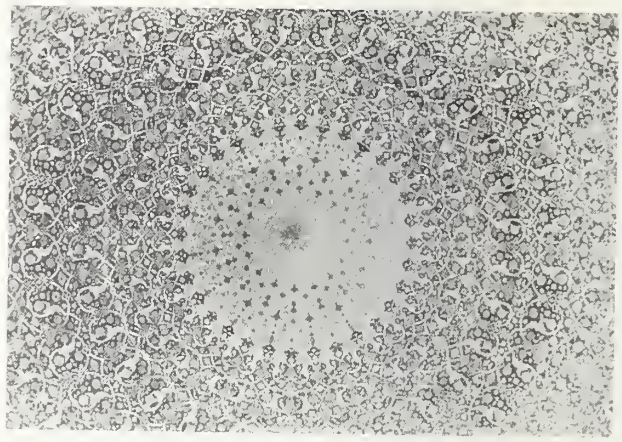

Figure 21

Figure 22

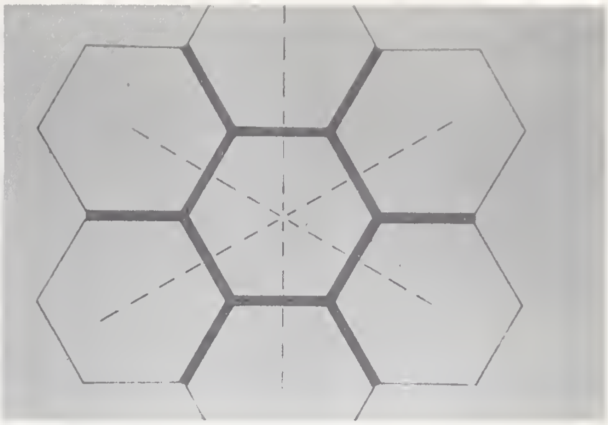

Figure 24

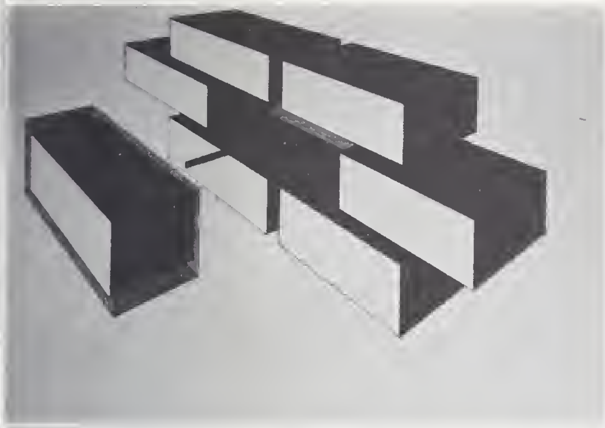

Figure 23

Figure 25

problem occurred many times and was solved every time, leads me to believe that it is the best alternative.

Place the responsibility firmly in the scope of one component. This may be difficult if one tries to follow present standard specification rules which are designed so that the architect gets his building divided up into neat, if somewhat illogical, packages—certainly illogical from the systems designer's point of view.

I would like to return to the subject of the geometry of the system. This should be part of the specification. I spoke about gridlines and adherence to the discipline they impose. There are center lines to be considered too.

In this example of a system component (fig. 24), you can see two separate sets of reference lines, those connecting the centers of the hexagons and those connecting the centers of the joints.

The grid may be expanded by moving the components along the lines connecting the centers and the same regular pattern will be preserved. It is this kind of basic geometry that one finds in the examples of eastern architecture I showed earlier. Our large system brick, which is a whole house or part of a house (fig. 25) has a geometry of its own (see figs. 26 to 35 and 36–37).

Figure 26

I have a further example of the geometry of a building system (fig. 38). Here you see that the designer studied the problem of the loading and positioning of a column. He decided that any area had common points at its corners and the logical place for the

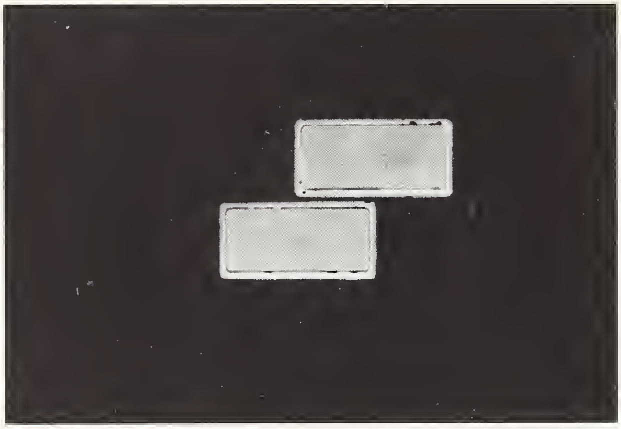

FIGURE 27

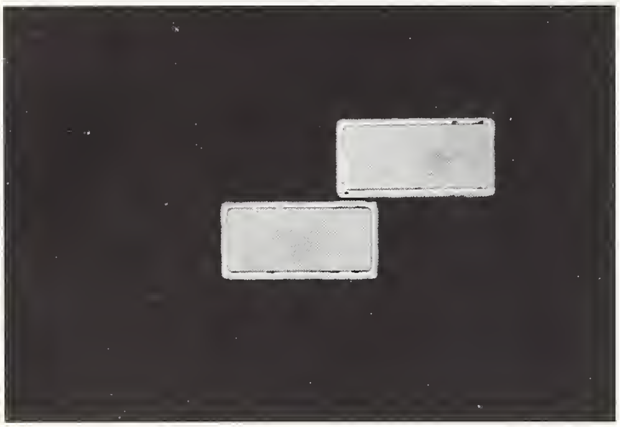

FIGURE 28

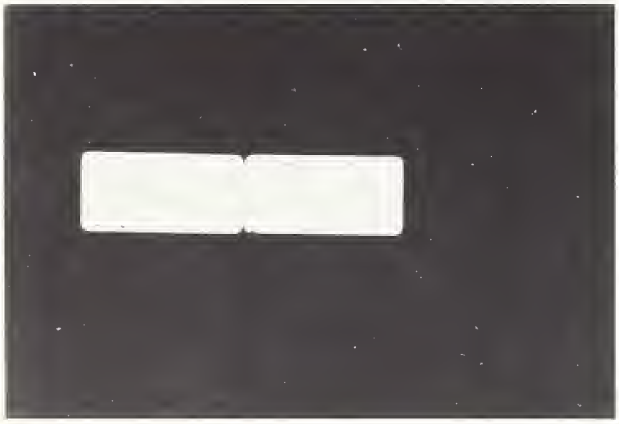

FIGURE 29

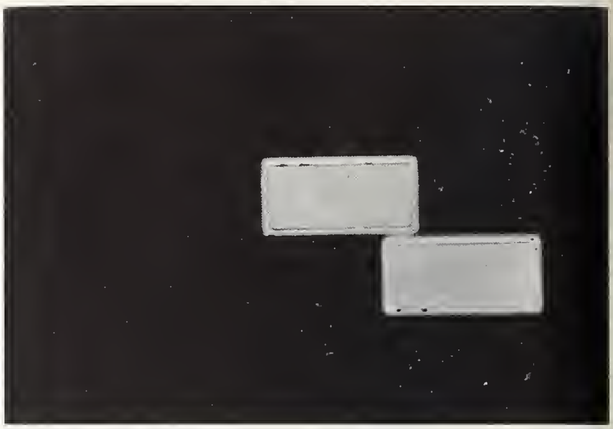

FIGURE 30

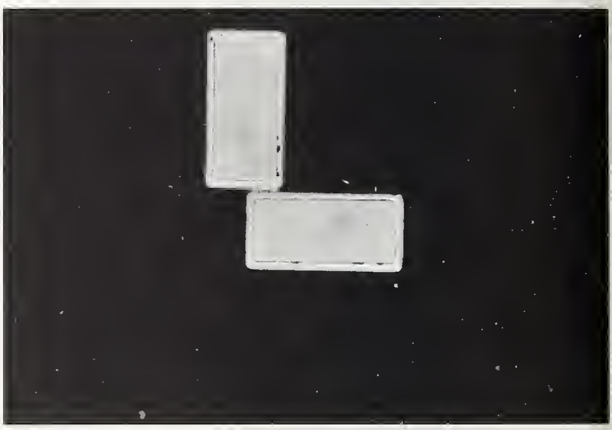

FIGURE 31

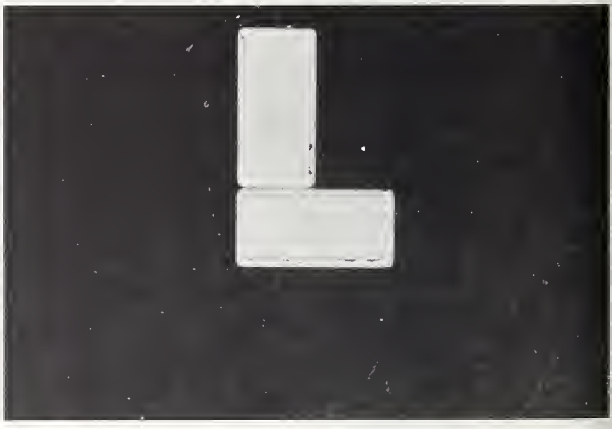

FIGURE 32

Figure 33

Figure 34

Figure 35

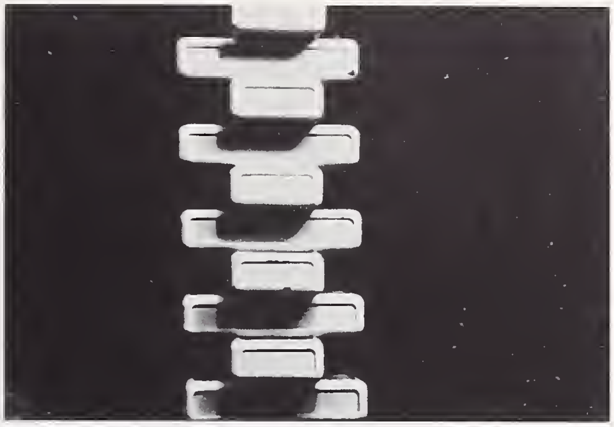

Figure 36

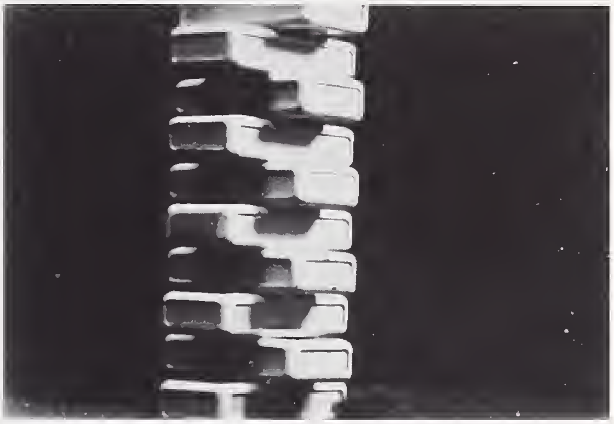

Figure 37

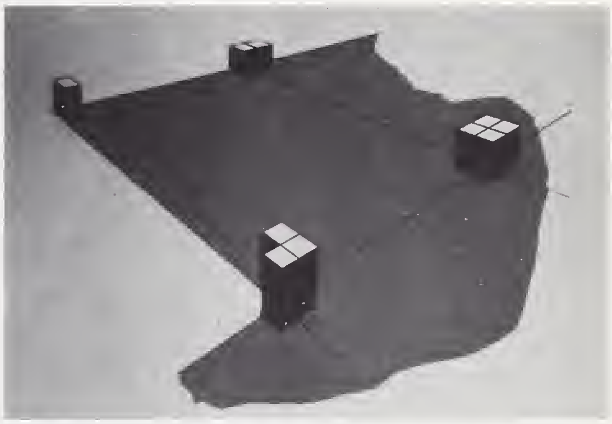

Figure 38

column was at the corner and within the angle created by two interface planes.

It was simple to see that all conditions were met by this logic and column clusters of one, two, three, or four columns were made. Between the column face and the interface plane, there is a gap and two gaps make a joint.

I see that my brief tells me that the dimensional standards are not to relate to particular products or proprietary solutions. Well the same rule applies: the component must end on a gridline of a modular system. You will realize that in a column and beam solution to a structure there are difficulties particularly when one comes to the end of the system.

What is one to do with the half column and half beam that are left over? I leave this to the ingenuity of the system designers. The Ancient Egyptians solved it. So too did the Early Greeks. It has recently been resolved in both of the HUD Breakthrough proposals I mentioned earlier.

In one of them, the designer reached the same conclusion as did the other fellow who produced column clusters, but his solution was to make one column the size of four, and use it as a projecting feature when it happened to be on the outside face.

Modern manufacturing methods often find it cheaper to provide extra material rather than to abandon a simple form. This seems to be a point not recognized by many traditional designers.

Systems building will be successful if machine work replaces handwork and scenes like this pass to the realms of the wattle and daub builders (fig. 39).

It seems appropriate to end with a picture of quiet beauty with only one systems building in sight (fig. 40). That's it on the left with its back toward us.

FIGURE 39

FIGURE 40

# The Missing 5 Percent

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"The Missing 5 percent" covers the significant technological developments already at hand, but not being used effectively because of the lack of integrated development and the necessity of creating the awareness of utilization via the proper marketing and distribution to enable local implementation. Further, case histories of significant programs underway or being developed on a nationwide basis with such distribution are presented.

Key words: Building systems; integrated distribution; technological utilization.

About the topic, the name of it—the idea had been jelling for a period of time after I heard a conference that I felt was very meaningful. But, having selected the topic "The Missing 5 Percent," I am not sure I can convey what I mean, but I will certainly attempt it. The idea came from a comment by Ezra Ehrenkrantz that, "One man's system is another man's component." Meaning that no matter what we do in our fragmented areas, the interface that we have talked about still has to be assembled. A key engineer stated that 5 to 8 percent of the cost of planning and designing relates to putting unrelated items together; but, it accounts for 40 to 50 percent of our time, and 75 to 80 percent of our problems with the finished building. It is measured in confusion, customer dissatisfaction, callbacks, claims, etc.

So, any discussion with reference to systems interfacing, or any of the things that we have covered today, certainly relates itself to eliminating these problems or we have missed our functions in defining needed standards.

I don't think we should run our industry down the way some of us do consistently. We're not quite as backward and naive as we lead ourselves to believe, and sometimes we do ourselves harm by letting the public feel that we don't know what we are doing. I think some of the things that you have heard here have been significant and many significant things are underway.

I would like to quote from a recent study that was prepared by Seymor Kroll Associates of 200 of the leading builders in this country. One section of the study is called: "Builder's feelings about the use of new and substitute products represent a very frustrating and paradoxical situation." On the one hand, the builders indicate that cost-saving products are definitely wanted; on the other hand, they admit their reluctance to pioneer in the utilization of cost-saving products. While indicating that they are really thirsting for ideas, they simultaneously report seeing few such products.

Complicating the situation even more, builders appear unable to define the exact product area in which cost-saving ideas are most needed. They look to firms for the conception in leadership and development of the product. It is important to note that even though builders are very receptive to new products (quoting Seymor Kroll), they will continue to be cautious in their acceptance of such products. They are emphatic in stating that each new product should be thoroughly tested and evaluated by the manufacturer or the designer before they will risk using it on any large-scale basis.

Also, builders feel that the installed cost of a new product must not be greater than that of the product which is being replaced. They feel that new products should have established consumer acceptance before they will use them. This leads to the dilemma of which comes first, the chicken or the egg. Consideration by the A62 Committee of product acceptance and development of testing is equally important to the coordination standards it develops. Also indicated is the need for controlled distribution at the contractor level.

In the September 13 issue of *Business Week* (if you haven't seen it, make an effort to review a copy), the heading was, "Is Breakthrough Near in Mass Housing." The subtitle under it, however, is significant. "Broad Spectrum of Companies Will Bid To Participate in HUD's Plan To Produce Low Cost Homes." The real hurdle is not technology, labor, land, or even mortgage money; but public acceptance. I think that this is the area of marketing and distribution that we have to take into consideration along with the product design.

So, if I can contribute anything today I will attempt to do so by adding another 5 percent, or call it the missing 5 percent, to the construction dollars that will have to be spent, to gain new product acceptance. Another 5 percent is necessary in order to provide the mass market that will make it attractive to manufacturers to develop and put a product on the market and then to convince the people that have to utilize it, as well as the customer, that it is a more satisfactory product.

I don't agree entirely with the builder's survey, that item for item new products must reduce cost, or be cheaper than the items which they are replacing. It is

the total system cost that is important; a new product can reduce cost elsewhere, even if one specific item costs twice as much.

But, the total industry is very complex and we always have a tendency to oversimplify. This is why it makes it difficult for committees such as A62 to try to come to grips with the problems. As I proceed, some of my comments may appear a little bit redundant and somewhat elementary, so I ask your indulgence. I want to excavate for the foundation before I put the roof on and move a customer inside.

I intend to discuss the need for the interfacing of the total fragments of the industry and not just the interfacing of the products. I think we have lived to see this, accelerating at an ever more rapid pace, during the past few years. We also feel that the marketing and preengineered product know-how, based upon experience in total marketing of preengineered building systems and their complexities, is a needed service.

I think that we have to look at the past and recognize some of the mistakes that have been made if we are to have validity in the future. Number one, we are seeing the same mistakes made over and over again. We are seeing everybody jump on the bandwagon and wave the flag because the President and the Kaiser Report said that we need housing. There is no doubt that we need it. We have needed it for years. We need better methods, but we have never fully established the systems already available, the marketing of those systems, and gaining acceptance for them in the climate in which we have to operate. I want to review past mistakes because I think that they have to be taken into consideration.

Number one, systems has been the word from 1967 on, but prior to that, from 1957 to 1967, preengineering was the word. When we carry it back further, before 1957, the word prefab was always used. Many in this room disapproved of it in 1957 and would never buy those "prefab buildings" because the word prefabrication meant industrialization and the building of components somewhere other than on the site and this was thought to be inferior.

It reminds me a lot of Cinderella, who sat behind the stove all dirty until the one night when she appeared at the ball. Today, all of us, from leading government officials down to the contractors, are running around like the prince, trying to put the slipper on the foot of things that have existed for years. I don't think we can ignore the past or advance into the future saying that everything we have done in the past is wrong.

I think there has been far too much emphasis on technology and production. This is part of the manufacturers' problem since they look at things from the standpoint of manufacturing and new technology. But, this new technology in many cases does exist. We do have fine products. In the past we have concentrated our efforts on sales and not total marketing. The essence of marketing is in concern with the total environment in which you have to make a profit. It is more than the production and fiscal administration of an operation.

I think that we have also been confused somewhat by the terminology of "open" and "closed" systems. Most of our experience in prefabrication has been with closed systems, the design of series of components around a very specific end-use purpose. Whether it be residential, industrial, or commercial, it makes no difference.

Another mistake is that preengineered building firms have considered themselves as manufacturers with responsibility ending f.o.b. plant. Actually, they are, and have been, only subsystem manufacturers and to make the matter worse, most of these firms have had uphill battles and have been undercapitalized. This too, is changing with the acquisitions and mergers that have been taking place.

The building product firms have a dilemma that you must recognize when you want to deal with them, and I am sure that A62, in working with system manufacturers, has recognized their problem as well. They have a great deal at stake. They have spent millions of dollars setting up existing distribution networks. They have invested other millions in their plants and equipment over many years.

In the past we have seen brand-name firms, which stand behind their products, come into being in our country. In construction we have to anticipate that this same thing applies; that responsibility cannot be f.o.b. plant and the manufacturer's responsibility has to include the installation and provide research and standards.

The whole industry is resisting change regardless of how we look at it. Even if the climate is right, social pressures are here, and it will take the concerted effort of all of the leaders of the industry. There will be resistance to change and with a failure to establish distribution at the local contractor level, as all of our basic industries have done, we will have a major problem.

He who controls the shell and controls the distribution of that shell, if we can predict the future, will control the sale of the other material. If he reaches enough volume, he is the man whose specifications the others, as parts manufacturers, will design to, because he is the one who can assure them of a market.

It is important to note that the whole purpose of a building starts with the customer. We have to look at the customer's budget; we have to know what the financing is; and we have to provide maintenance and continuing service for the life of the building. Guarantees and warrantees have to be provided in a well-designed, well-conceived, living or functional unit. Now, where does this customer go when he decides to buy a building?

He can go to an architect or to an architect-builder. He can go to a package builder, or, in many small towns, directly to the general contractor. Whoever he goes to will, in turn, have to deal with building product firms.

Building product firms are trying to market thousands and thousands of products and communication is very difficult. They can market by direct distribution. Some do. They can market through a dealer

network, or through a subcontractor. The subcontractor is a very important element in the specifications of products today.

The rest of the industry must be dealt with. Things such as the following must be considered: Land; financing; insurance; government; subcontractors for material and mechanical equipment; labor; investors; and arranging for leases and contracts. Today there is property management and the joint ventures of any one of these working together. The end result for the customers is to put it all together and obtain a building—promptly, efficiently, and at low cost, if the customer is to be satisfied with his purchase.

Even a small contractor working from his pickup truck has to be quite a manager if he is to stay in business. The industry is highly fragmented. Each of the groups is oriented in its own discipline. It has been a highly specialized fragmentation and there has been a lack of understanding and communication between groups. This is confusing to industry specialists and more so to the customer. If mistakes are made, whose fault is it? Whom do I call? Whom do I blame? Whom do I go to see to get results?

As far as I am concerned, the true manufacturer of buildings at this point in time, if manufacturing means delivering a finished product to the customer, is still the contractor. Demand and inflation have created a climate necessitating basic industry changes requiring total industry coordination. If it is to be coordinated, I think that the A62 Committee will have to move very rapidly because the industry is moving fast. If it performs the function that it can perform, it will have to move aggressively and not put this in staff conference for the next 5 years, because 5 years from now we will be talking about a horse of a different color.

The construction industry, exclusive of roads and public works, is the largest industry in the country. Residential construction alone is second only to the automotive industry. We saw Mr. Burton's film yesterday about how autos are made. There is always the comparison of any industrialization with automobiles. Autos are a finished product, ready for delivery to the customer, when they roll off the line for that final inspection.

In 1921 there were more than 500 automobile manufacturers—I think it was 522 to be exact. Where did they go? They complained—about financing, sales, and distribution, and government programing for roads—just as we are complaining and looking for aggregations of land, service, and eliminating the customer resistance to change. The depression took many. But, the change only came to the automotive industry when some firms began to acquire others, and developed capital depth, improved management, and developed marketing with local distributors responsible for sales and service under firm discipline of the company. In other words, that industrialized system on four wheels went out to a local distributor organization that was fully responsible, knew the local codes, knew the local situation, and was in a position to furnish the customer's need and provide the automobile. Hence, we have the tremendous automotive industry today.

We should also look at the fact that the automotive industry became as big as it is and as efficient as it is, and reduced the cost of autos down to the working man's level but there are very few manufacturers left. Now what are some of the trends of which we should be aware? The essence of marketing is change. We, as leaders in the industry, if we are going to participate, must recognize change and condition the public for it.

Our fragmented industry seems to be becoming less and less fragmented. Architects are hiring engineers, and engineers are hiring architects. Both are becoming builders. Building firms are hiring all three. We have major capital coming into the industry. Realtors and land developers are diversifying. The insurance and financial institutions no longer want just a mortgage, they want ownership and participation. The insurance and financial institutions want to control their money for the long range investment and to see that it is properly managed.

General contractors find that more and more work is being negotiated and not bid. Such changes are significant and will have tremendous impact. The customer wants single-point responsibility. Because of this, the contractors are having a great deal more to say with reference to specifications and utilization of products. So, unless the customer and contractor can be made a part of the team for developing standards and acceptance, we can anticipate problems in marketing.

Everyone is playing with building systems—even government agencies which control large building segments. Mobile homes and sectionalized homes are the vogue. Low-cost housing is constantly talked about, but little action is taken because production and technology are not enough to beat the battle of inflation and the many profit centers now constituting the industry.

Finally, as far as trends are concerned, the average builder is just tired of keeping up with this present activity because our technological developments are accelerating very rapidly. The essential question each fragmented group must answer is "Where do we want to go?"

Opportunities abound in all directions. Now, let's look at what is happening. The customer is still there, the building is still his goal. We are beginning to see distribution patterns break down and overlap. The building product manufacturers are feeling the temperature of the water for systems. They have a great deal of money and experience at stake in the construction industry. They are willing to work with A62.

The price and application of materials is under attack. The methods of specifying are shifting. If we don't move as an industry, we can predict that the social and economic needs in this country, as in Europe, will force the government to take steps toward a more active role. Customer needs are being recognized. We can't just build a building—we have to determine the functional long-range customer requirements. Some firms are facing this dilemma, not all, just some of them. And finally, the social and economic

pressure upon the unions and codes are creating a more favorable climate for systems and their acceptance.

Now, concerning money, and the significance of it coming into the industry. I refer you to the June issue of "Automation in Housing." Over seven pages of fine print listed the mergers and acquisitions that have taken place in the last 5 years. It is very significant to note the firms that have moved into the industry. More significant, however, is the fact that many of the firms are not historically oriented in the construction industry. This, in many ways, could be good because such firms can be openminded in their approaches. They do not have to justify to the board or to the stockholders, why they declared certain machinery, tooling, or equipment as obsolete. The capital is coming in and the many profit centers are beginning to overlap and be merged. As the firms grow and merge, control and mass markets will come about. This is, you might say, the period for acceptance of systems.

Because systems manufacturing and development is a very complex and expensive program, proper planning is essential. Many of the firms already in the industry, and firms new to the industry, are putting acquisitions together. It is significant to watch patterns. This is being done because the industry is going to be a growth industry. Many anticipate that by 1975 there will be strong profit centers. Putting unrelated items together with proper handling could result in a situation where the best of all diverse acquisitions come together in systems, which means more profit. This can be done by either acquisition or development.

Presently uncommitted companies have an advantage by not having capital, tooling, and distribution channel paralysis. What is really significant, however, is the long-range objective of turning all into properly developed, profitable systems. Once achieved we will then have a situation where leadership and standards can come up with new opportunities not yet possible in the industry. It must be a full commitment if a firm elects to go this route. They will have to spend large sums in a very complex industry.

We mentioned 1,500 items that went into the auto yesterday. Well, the typical prefabricator today (and by the way, there are a few of those guys around, and they do have some experience) is coordinating an equal number of items in a home. So it takes a great deal of money. Either direct or dealer control at the local levels will be required for controlled distribution and sales projections to warrant the investment. You can come up with a better mouse trap, you can come up with any concept, any system, but unless you are assured of a certain repetitive volume it will not warrant the investment. So, you must begin concurrently with a product design, its marketing plan, and the long-range system programing to assure marketplace, customer acceptance and stable production.

Except for monumental projects, the architect, the engineer, and homebuilders are being overwhelmed by the accelerating changes in technology. The need is for simplification in construction programing and design, necessitating the increased use of compatible preengineered component systems.

System's development is taking place (you can't pick up a trade journal, newspaper, or real estate section, that has not jumped on the bandwagon) and the time for us to move is now! Further growth in the industry, utilizing organized national programs, will enable the utilization of marketing techniques proven by all the major industries in the United States.

Firms that lay the foundations for such programs today will be in position to capitalize on the new potential that is being generated. But, there is a vital and most important thing for you to take home, if I can impart it. A true mass market that would justify mass production of systems calls for stability and predictable distribution under some long-term systems discipline. Such discipline is not found in the monuments, but is the building technology that underlies every building structure, no matter whether its function is that of housing, or whether it is a service function or a manufacturing operation.

Money and time must be spent to market any system already developed or being developed. And we can't say that everything in the future is virgin. A great deal does exist! It is important that we evaluate what does exist and put our weight behind it and make it effective. We must do this, if for no other reason than the fact that the existing systems discipline has established some distribution, and this distribution network is in the marketplace today. It can be made effective if properly directed.

Instead of talking about joists or floors and so forth, we must talk about a complete foundation system or a floor system. Can you imagine the market potential if the builders in this country purchased the total foundation as a system. Forget the house, first look at the foundation system mass produced as the proper way to go. The market potential is staggering for the firm that moves in such directions. But regardless of how we talk about systems, it is important that we recognize that the change will be both revolutionary and frustrating. It will not be a crash program—there will probably be no initial saving, no magic formula for profit. It is going to be a very plodding, deliberate program.

It is essential that we establish a long-term goal, and I think that this can be done by the A62 Committee. The ultimate scope must be determined first and worked backwards. You cannot move from this point to that point in small increments and end up two-thirds of the way through, somewhere you don't wish to be. I think Michael Clarke said yesterday that in England they started their technical standards program and got to the point of function, and they then had to backtrack and move into the functional aspects of the program. All aspects of total scope must be considered before moving. Our sitaution today reminds me of a joke: As a plane was flying along, the captain's voice came over the loudspeaker with a word for the passengers. "I have both good news and bad news. First, I am going to give you the bad news. Ladies and gentlemen, we are hopelessly lost. However, for the

good news, we are 20 minutes ahead of schedule." I think that this is our problem today. We are accelerating too quickly. We are not hopelessly lost, but I do think we have to put our feet on the ground and evaluate just where we are and what does exist. We must exploit those areas where the most progress has been made and begin to develop a system network maximizing the efficiency of contractor elements. I say contractor elements, they may not be the contractors we have today, but they are the people who will not be eliminated from the local site assembly process regardless of how industrialized we become. So, to the contractor who erects the building, perhaps this "one man's system is another man's component", will merely mean that the items to be assembled will be fewer but more significant.

We will still have local marketing, the distributor. and the contractor who at the local level will be an essential element of any team.

I think that we have to look at standards. Mr. Hughes has just covered the subject very well. We must move to subsystems as large as possible as basic as possible as basic components and then from there to standards for the total system. This would be my recommendation to A62.

I do think it is important that we understand exactly where we stand with reference to certain definitions. These are our definitions. Many of you may disagree. A preengineered building is one where the waste is left at some spot other than the building site. The components fit into place without cutting or fitting. A preengineered system, flexible enough to be adaptable to many different use functions, codes, and interior arrangements, would, in our terminology, be an open-component system. A preengineered building, tailored to a specialized end-use or market, and with a need for repetitive sales of a specific design is a closed component system.

A preengineered building manufacturer, essentially a firm or group of firms that have developed a marketing plan and a closely knit, well-informed sales and distribution organization, sells buildings of preconceived component design concepts. This does not mean an end form design, it means design within a component concept. Such a firm is essentially the coordinator of all components and parts, whether manufactured by the firm or purchased to its specifications.

When we talk about the contractor at the local level, he will be a contractor or builder approved and franchised by the preengineered building manufacturer or supplier. He can be directly "company owned" with a primary area of responsibility for the sale and construction of buildings utilizing some basic building systems or an independent controlled user of the system.

There is a great deal of feeling that nothing has been done in systems. In the industrialized and commercial areas today, we have some lessons to learn—particularly in the area of distribution. We should also look at the real direct impact a similar distribution program would have on the residential building field. Regardless of whether a building is residential, industrial, or commercial, it is still a building. The only difference is that residential buildings come much closer to meeting the functional requirements of a housewife.

Some of the mistakes that we have to watch out for are: The lack of specific market research; design negligence; unrealistic pricing; not selling the financial lenders. In other words, even in systems you have to start somewhere to develop the brand-name image that you need. Other mistakes are: Advertising without an overall theme; failure to advertise at all; failure to recognize trend changes in the market; lack of professional sales management knowledgeable in the total construction process and not just a product; misunderstanding the total construction process; and neglecting the post sale followup.

Once a customer buys, he is the best salesman that you could possibly have. We get so wrapped up in technology that the customer is often forgotten. It is going to be his money that is going to buy or make the payment. Unless adequate consideration is given to the customer in the beginning, we can forget any program. It is the customer that has the building need.

I would like to touch briefly on the metal building industry. They have developed a distribution network in excess of 3,600 contractor-dealers throughout the country. They are so strong today that, regardless of brand affiliation, the dealers have formed their own dealers' association. If you look at the metal building industry very carefully, you will find the concept of "he who controls the shell . . ." It has organized engineering discipline and local distribution. With construction capability, such as the metal building industry has, an industry is able to achieve national marketing impact.

This industry should be looked at very carefully because it has been very successful. Metal buildings, for the last 4 or 5 years, have increased in number at a rate of 25 to 30 percent. Today they account for 12 to 13 percent of the total industrial and commercial sales of single-story structures within this country. Many firms are introducing two-story structures which would have been unheard of 2 years ago. They are able to do this today because their dealers have gained such a foothold in the community and they negotiate sales. In other words they have become a contractor with a sales force.

Essentially, the metal building industry today consists of organized preengineered systems programs with manufacturing capabilities, industrialization, and the marketing tools to support the local contractor and the building manufacturer.

The future of any system will involve turnkey buildings. The customer will want and demand total design, contracting, and service responsibility. Firms that move in that direction will find that they have taken a step toward success. All systems and the materials discipline must find their own niches. There is no such thing as an all steel program, an all concrete program, and all wood program or an all plastics program. Each of the materials have certain functions which they can best perform.

We move into the area of open systems or closed systems. The ideal solution would be mass production of open systems with tremendous flexibility in application. Open systems provide for the tailoring of buildings to required functions. But in open systems there is underutilization of basic components. Some of the portions of an open system will exceed specific use requirements. Closed systems can more exactly meet requirements on a regional, area, or a very specialized basis. You can also take the best of the open-system's components, mass produce, and develop closed or rigid application that will be required.

The key to the success of any building system will revolve around its distribution plan. In essence, open systems planning and development will be more extensive engineering-wise and more expensive to develop. Closed systems will be less expensive but less flexible, and the competition will be keener.

To predict direction, look at the existing metal building industry and study it carefully. There are other programs as well. The American Plywood Association has developed its wood systems program. Pre-Cast Systems Incorporated has been developed as an offshoot of the Pre-Stressed Concrete Institute, which involves capitalization for programs and systems development on a standardization basis with 42 member firms affiliated with it. The American Wood System is going to involve between 22 and 27 manufacturing operations nationwide. All of these programs recognize one of our problems, distribution.

There is a need for national geographic coverage because of the cost of marketing. There is also a need for centralized computer engineering and research, and it is very expensive. Then, there must be local manufacturing with an aggressive, well-informed distribution network of local contractors, which I have harped upon.

The metal industry has it, the wood industry is moving toward it and so is the concrete industry. They are trying to solve some of the problems. I think we should look at what they are doing and if they need help, give them all the help we can, because they are expending the money and moving.

How do we implement a precoordinated building program? We must put together all of the engineering and manufacturing and tie them together with the dealer-contractor program. To do this, there must be coordinated communication, cost control, planning, and precoordination, and a great deal of it. The contractor must have a very strong relationship with the design team.

Now, in moving to systems, essentially, we would have primary framing systems. They could be alone, or they could be in conjunction with roof systems, wall systems, or accessory systems which are causing most of the problems. There is a problem in trying to get the manufacturers to work with them, but there is also a problem in developing enough volume to be really competitive with the local installers and the materials that are already tested and proven in the marketplace. This is a major obstacle.

The goal should be to develop large component systems with subinterfacing relationships to other systems. Such internal interfacing should be the responsibility of the manufacturer of each system. Further, if properly integrated as part of an open system, a component system (be it the roof system, the structural system, or the wall system) can stand as a separate entity.

Now, we are approaching true mass marketing. The structural system can be utilized if that is what is required. If you want to go beyond that and integrate the total, it should and would be a proprietary system. At the same time, you should be able to break apart some of the systems.

Now, moving to some of the typical systems, I am going to run through them very quickly. As engineers, we are all familiar with them. The metal building industry has developed a structural system which was nothing more than the rigid frame first, and then a tapered beam application. What is important about this system is its utilization of the manuals and the engineering data that exist.

We have examples of the utilization of technology now in the industry. Metal structural systems that have worked very effectively, and now are on a 5-foot-modular basis, include ceiling system, lighting system, heating, air conditioning, and ventilating. In other words, because of the basic engineering that existed and the distribution network, the system is being further exploited and can be even further exploited. Others can do the same thing.

Turning to the wood system—it is a system based upon, surprisingly enough, steel columns. When this system was being developed it was quite startling to find out that practically all of the basic engineering existed already on tables and charts. It was a matter of providing interfacings, connectors, joints, and putting things together.

Flexibility and separation of elements must be provided. Framing systems must utilize the same basic system incorporating standard components on a repetitive basis—for example, the same post and beam, basically repetitive in nature, but with flexibility inherent in it. Tapered beam systems must provide component selection so design can vary as the load; also, the functions applications.

The more esthetic and flexibile, the more thought that has to go into the planning of a system. But, the panel system, the roof system, the wall system, are all capable of being preprogramed or precoordinated.

Because some of us have stereotyped concepts, we feel that a prefab system is inferior—that as a designer or an architect, we lose latitude for design. A precoordinated system is no more than an interrelation of basic subsystems which are, in turn, interrelations of components.

Now, in all of them, it is important to note that none of this is really new. All have existed. It is the engineering that brings them together, and the marketing and distribution to provide the volume that is needed. We continue to perpetuate the mistakes of the past and place emphasis upon the technical advances. In essence,

percent of our construction and management effort should be directed to the marketing systems.

It is not technology, but informed and trained distribution that will lay the groundwork for the mass market, which will then substantiate the investment, which will fully exploit building systems and begin to make building cost reductions effective.

What is necessary to support this type of program? Unless you have looked at, let's say the engineering data and the full set of manuals that are made available by a fully developed system, you may be surprised. For example, material that is essential to a metal building dealer runs all the way from the complete statistical tabulation of computations on design (that can be turned over to the State inspector or local code official) to administration and marketing data. Cost of data exceeded a million dollars on one system compared with only a million and a quarter in basic tooling requirements, less plant which already existed.

This may give you some idea of the extensive amount of engineering data that has to be put in the hands of builders at the local level. Under the American Wood Systems Program, the same type of thing is developing—operations and technical manuals encompassing all of the engineering data, chart selection, computer numbers, and a corresponding price book to aid the designer in selecting the interrelated components required to complete the total building system. Fabrication manuals and shop drawings, advertising at the local level, sales manuals, and sales information are all required.

How does a system convey to the customer (in order to help him in his selection of buildings' requirements and functions), necessary information concerning such things as landscaping and lighting plans and bring to the contractor-customer level the expertise that is required. All of this has to be done to make that local distributor effective. The key for entry into this type of program involves dollars and management know-how. That is essential if any program is to be effective.

Any system must have the capital to industrialize, to stabilize, and to develop management and long-range planning. If industry can't get it off the ground, and venture capital is not willing to do it, then the government is going to have to step into this role.

As the whole construction process is a system, we cannot think of a system merely as the post and the columns or other functional elements. We must look at the total system as a functional unit as it is lived in or utilized in place. We must lay enough of the groundwork to make distribution effective. Systems have to have something to sell, and we must make sure it will be sold. Beyond that, we must have the long-range research and development to fully exploit systems marketing potential.

We must have the long-range plan to develop a profitable program. Without a profit, we will not succeed in our capitalistic society. We can't do it as Russia does, by decree. We already have people to coordinate products and to develop and manufacture them. What we have to have now is participation. No one firm, or no one group in the U.S. building industry can do it alone.

HUD is pulling together eight or nine firms for the first time. Now, whether HUD's breakthrough becomes effective or not, it does get the firms together and shows that they can work together. This is very significant but, essentially we must establish the policies under which we want them to work.

In summary, I think it is necessary for each product discipline to find and exploit its own advantages. For systems and precoordination to work industrywide, it is essential that we start with the customer. It is essential that we start with the knowledge of the complete scope of end results desired, regardless of whether the target date is 10 years away. A successful program must start with the end results and plan backwards, even if we have to do this in phases.

We must recognize that far more than basic material discipline or technology is involved. The mass production that we saw in the automobile film yesterday is not here. We all have to move directly to the customer and take into consideration his requirements. If we are planning for any type of breakthrough, and I am not using HUD terminology, it will be evolutionary and not revolutionary. Distribution and organization must be created first. This requires either the direct ownership and control of construction at the local level, or national precoordination of affiliated people and dealers with marketing and discipline. Then, once we have that, we add additional items.

There must be strategic marketing plans for volume and they must be tested constantly as we develop the systems programs. The total concept must be broad in scope with flexible end-use application. The day of considering the brick or the block as a component is gone. Preengineered to production standards with maximum design flexibility and with the minimum number of parts is the order now. It is not an inexpensive program. A firm should carefully weigh and be aware of the total commitment required. The industry has been hurt by too many halfhearted attempts. A technical solution without the marketing and the distribution plan is prone to failure. There is no quick way to revolutionize buildings with a new wheel.

We must recognize that it is going to be expensive considering the costs of the following: Engineering; construction; marketing; inventory funding; transportation or special trucking requirements; material handling; extensive distribution costs; training and development costs; code clearance programs costs. On an organization basis, even with the computer, expensive structural calculations are required. Also, the hiring and the training of the personnel requires considerable coordination from an administrative level.

While much of this has been pioneered by major firms, they have not had enough at stake in the past to go the full route. We feel that they are on the verge of doing so. Emphasis must be on programs, not projects, and on repetitive volume. Success must be based on product standards. Standards for compatible systems and components must be aimed at making money,

and they must satisfy the social and economic needs of today and the future.

Opportunities exist, but many questions require answers and a definite plan should be established that is compatible with the long-range desires and capabilities of any group of firms which are sponsoring such a systems program. Frankly, we should all be glad to be part of such an exciting time and have the opportunity to really develop systems programs, but we should not be stampeded.

The experiences of the past can hurt us only if we repeat mistakes. The future will belong to those who plan for change and for an integrated building system or a subsystem service thereof. The mass market is in the hundreds of buildings built everyday in every shape and form, in every community of this country, and not just in certain major areas, or shall we call them urban programs.

It is essential that all of us, that this A62 Committee, throw its weight behind firms that have the potential and the desire for full-scale penetration and systems technology. All product managers and all product manufacturers can benefit. I am talking about the start of this new precoordinated system program. But, if the management outlook is one of "this new market is insignificant and not worth wasting time upon," the manufacturer that takes that attitude will not necessarily be a part of the future growth.

It is our experience from working with some of the firms which are trying to develop building systems, that many of the manufacturers of accessory units or items that become a part of a system, have not been willing to work to the degree necessary for real precoordination. In the changing or modification of their products to fit the systems, they are reluctant to spend the time and effort to work with the building systems manufacturer. This is an area that will have to change.

If the utilization of precoordinated components in residential, industrial, or commercial building is to be achieved, both a closed and a nationwide open system will evolve. But, the closed systems will in all probability utilize the open system. In the chicken or the egg connotation, we feel that only when we evolve complete coordinated control of distribution programing, will we be able to concentrate on the known market and generate sales to justify the true technical precoordination required.

Perhaps I have missed the point on the missing 5 percent. But, I have tried to present the essence of marketing and the role that it will have to play if systems are to be successful. If we spend the 5 percent on marketing, I have confidence that the technical problems, using the technology that does exist, can certainly be solved by a nation capable of putting man on the moon.

# Approach to Architectural Design

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It is obvious that "precoordination and industrialized building" will affect the architect's approach to design; therefore, this presentation attempts to explain a method of component assembly construction which will allow unlimited design variety within the "systems." Dimensional coordination will be examined in terms of number relations—a means of dimension coordination; component modulation—a means of component systems coordination; and, common denominators—related to function and building types. Then, conclusions will be drawn regarding the above tools and methods for design discipline as a basis to relate components in different ways to achieve variety, flexibility, and economy.

Key words: Design modulation; industrialized building; modular precoordination.

## 1. INTRODUCTION

The industrial building age is present. It's about time. Every architect strives to achieve humanism in architecture. If architecture appears cold or the building appears too industrialized people feel uncomfortable in these spaces. There are several ways of achieving humanism in industrialized building. We use age-old design principles: proportion, repetition, alteration, rhythm, harmony, contrast, and balance. We use different materials, textures, colors, mass, scale, geometric shapes. This gives us a response to our physical senses and with this we create different moods and express different feelings.

Architecture can remain an art. Expressed with industrial components, it becomes an even finer art because we are speaking in a new dimension. If we speak in a new dimension, we must use a new language; therefore, the approach to architecture has to change. Industrialists and component producers must work closely with sensitive architects so that this humanism is not lost for the sake of production and economy. It will do no good to precoordinate or industrialize if we lose architectural character. People will not buy!

In our own age, it seems we have such an abundance we do not realize enough good architecture. This is because we seem to have no limitations. If we were to work within a discipline, I feel a better architecture would be produced. To produce under this discipline of precoordination, we must understand the nature of industrialization. To sell requires public acceptance; a market. Good architecture will be accepted in a shorter space of time. This is the reason why I chose to talk about architecture in relation to precoordinated building.

If we have industrialized construction, without architecture, then the buildings will have no spirit, stimulate no physical response, no feeling, and perhaps be rejected. This will set industrialization back 10 to 20 years. Today we have a tremendous opportunity because of economic forces and tremendous need. The only question is: Are we mature enough to understand and express in unity the architecture of the seventies?

My presentation is based on my experience as a research architect for Southwest Research Institute several years ago.

It deals with precoordination as a means of attaining greater design flexibility. This is done by using a series of dimensionally and functionally compatible and interchangeable components, possibly manufactured by different manufacturers, that assemble into subsystems, that are in turn coordinated to assemble and form a total building system. If we are to have variety in our finished product in industrial building, it is basic that we should have variety in our modules. Our units of measure must have variety, and they must be compatible. They must be interchangeable.

I would like to start with a very basic illustration here that deals with the control of the elements of any building you are designing whether it is a church, a school, a house, whatever. There are three things that control it. They are quality, space, and budget. You relate these three things to the building design, people function, and environmental control. With this in mind, I will proceed with the presentation of some tools.

## 2. THE NUMBER PATTERN

The number pattern is a tool indicating the relations of numbers and selected modules, a means for establishing component and planning dimensional ranges. Once the basic unit, or module is chosen, the numbers in the pattern indicate the modular unit relations and serve as a means of securing the required sizes. The pattern indicates additivity, divisions, and multiple combinations of the numbers. This device, therefore, provides an effective means of reducing dimensional variety and a simplified method of securing coordinated dimensions. The number pattern is applicable for design composition, detail and construction coordination, and manufactured product size range selection. Thus, it is the common link between architect, builder, and manufacturer. The contractor can also use it in programing his construction layouts.

## 3. THE NATURE OF MODULAR COORDINATION

In order to use an efficient coordinated dimensional system for construction, we must first understand Modular Coordination—We achieve dimensional coordination by means of a module. Properly used, the module sets forth a means for expression, a sense for efficiency, and a quality of unity. The outstanding characteristics are discipline, simplicity, and order. These principles are:

1. Simplicity—a means for efficiency.
2. Order—a quality of unity.
3. Discipline—the means for expression.

A lack of this understanding in applying modularity might inherently result in a definite restriction on design freedom. This is obviously true. Therefore, one must understand the nature of "modular coordination" as related to design. The technical state of our times influences the plan and determines its details. A dimensional discipline requires only that a designer must know how to adopt the composition of a plan to the technical and material components and systems.

### 3.1 Simplicity

Simplicity is not so much plainness as unity of purpose. The inherent quality of the modular design simplifies the process of achieving properly coordinated volumes. When proper volume relationships are achieved a design appears aesthetically natural. Properly coordinated volumes are perhaps the most necessary architectural quality a building can possess. If available components already have these relationships, the designer's job will be eased.

In developing modular components it is necessary to have an understanding of construction and material tolerances. This understanding should produce a combination of simple tolerances functionally acceptable for precoordinated assembly. Herein is one of the keys to efficient successful coordination. If the common denominator, the module, fits and the tolerances are coordinated, then the components and the spaces within become coordinated in a simplified manner.

### 3.2 Order

In design there are two types of unity, static and dynamic. Static designs are based on regular repetitive patterns and on uniform continuity. Examples of static unity are such structures which express regular geometric shapes. Dynamic designs are based on fluent expression as a generating nucleus. Plastic continuity as expressed in Frank Lloyd Wright's work in dynamic unity. The Solomon R. Guggenheim Memorial Museum perhaps is one of the most expressive examples.

Now let's see if we can apply static and dynamic order to the modular coordination approach.

Static and dynamic order may be obtained by application of proportion. Static proportion involves the use of simple whole number ratios; i.e., 1 : 2, 3 : 5 and so on.

Dynamic proportion involves the simplest irrational number relationship. i.e., 1 : 2, 1 : 3 and so on.

Because assembly line production is especially suited to whole number ratios the developed module should allow for the use of static proportion.

Irrational proportion would be difficult and perhaps impracticable to achieve economically. However, certain of the irrational proportions come so close to being whole numbers that by rounding off they too may be expressed in whole numbers. Thus these also would lend themselves to industrialized processes. This reduces the restriction for unity on design and perhaps will exert a smaller limitation than exists today by use of stock materials.

### 3.3 Proportion

Design is the art of relating or unifying contrasting elements. One principle of design is a law of the relationship, or a method of organization, that determines the way in which the elements must be combined to accomplish a particular effect. Proportion is this principle of design.

Proportion belongs to form, not to matter, and where there are no parts there can be no proportion. Proportion originates from composite parts and their relation to each other. There must be at least two terms in each relation. Proportion, therefore, is the designed relation of measure.

Since the goal of coordination is the coordination of measure, the principles of proportion should be inherent in the system developed. This coordination, therefore, should allow freedom of proportion in design.

Therefore, from the standpoint of design, the best possible division of a line, surface, or volume, is one that creates two basic qualities, "unity and variety." These are achieved by proportion application.

Ratios used to create proportion must be selected with discretion, or in application they may create unnecessary disciplines.

Ratios are a means to an end, not an end in themselves. The system developed, therefore, should not be forced to fit particular ratios. The ratios should be obtainable from the system to fit the purpose.

The number 5 has qualities related to proportion. The 3, 5, is the basis of the Fibonacci number series. This series is rooted by the "golden mean ratio," a widely used ratio to produce pleasing proportion in architecture of the past as well as the present.

### 3.4 Discipline

"Discipline" is that element of design used to produce character. Thus, if we wish to express a formal character, or an informal character, for a building, it may be achieved by the degree of discipline imposed by the designer.

Such design principles as repetition, alternation, rhythm, harmony, contrast, and balance might be considered in this area.

In order not to limit design discipline, the modular grid system must be capable of being flexible. The composition effected by the visual and sensed flexibility should be inherent in systems for precoordination.

## .5 Modulation Means

The problem is not to determine which is inherently best, but rather what mean, or means, is best suited to the particular planning and constructions. Basically, four modulation means have been developed:

Mean 1. Rigid multiple. (Dimensions are based on the multiple of one planning module.)

Mean 2. Combination mulitple. (Dimensions are based on coordination of the multiples of more than one planning module.)

Mean 3. Additive. (Dimensions are based on the additive quality of more than one planning module and their relation to each other.)

Mean 4. Composition multiple-additive. (Coordination achieved by the use of more than one module incorporating their multiple and additive qualities.)

Mean 1—Rigid multiple: This mean is the most rigidly disciplined approach to modular planning. It produces a reference grid pattern whose grid line spacing is of a fixed order of magnitude. This requires a pure multiple application of the planning module. By nature this is similar to the classical and formal planning techniques of the past.

The selection of this particular mean is dependent upon the design plan type evolved to satisfy the functional specifications and plan type.

Mean 2—Combination multiple: This mean takes advantage of common multiples of two or more basic coefficients. However, for efficiency the number employed should be kept to a minimum. The employment of more than one planning module relaxes the degree of planning discipline necessary for modular coordination in building system precoordination. Further, it allows more than one possible solution to a given space requirement. This relaxed discipline makes possible the modulation of the building elements as independent planes. These planes then are coordinated on the common multiples of the particular planning modules selected. Also, spaces can be modulated independently. Finger-type plans lend themselves to this method of modulation. A floor element modulated by a 3-foot module and the ceiling modulated by a 4-foot module, are coordinated by their common multiple 12 feet in the wall elements.

Modular application can be achieved by a variety of means. In isolating these, we can study the effect of their application on space planning, material application, and building element coordination. An understanding of the basis for direct application of modular means indicates their limitations and possibilities.

Mean 3—Additive: The additive approach is applied in planning where the nominal space requirements do not occur in modular dimensions.

The dimensional relations required are achieved by placement and composition of the planning modules. More than one planning module is necessary to modulate by this method. The number pattern and combination tables are employed here as an aid to solution.

Several solutions are possible, dependent upon the functional and esthetic aspects. Here the grid becomes a composition grid which expresses construction of the modulated element but not the building construction as a whole. Therefore, the planning could well be accomplished without use of a grid.

Mean 4—Composition multiple-additive: The multiple-additive incorporates the advantages of Means 1, 2, and 3. This allows a flexible discipline. The discipline is then controllable by the architect to suit design and construction requirements.

This method allows the greatest degree of freedom to the architect but requires the greatest skill to accomplish the desired coordination.

## 3.5 Building Elements

The nature of buildings and the materials which compose them certainly effect the development of a workable practical system for modular coordination. The building elements as defined for this purpose are the structural frame, roof, exterior walls, floor, and interior walls or partitions. Each element might be composed of several different kinds of materials which create a particular type of construction employed.

When a single module coefficient is employed (this has been termed "Mean 1, Rigid modulation") to modulate the whole building, a high degree of discipline is necessary for design, selection of material and assembly of construction. The complete building and modulation system becomes a series of compromises of various degrees. An example is the use of the 4-foot module. Should a 30- by 17-foot room be desired, a compromise would be necessary. The room then would become 16 by 32 feet or 20 by 32 feet to suit the modular system. A material which does not construct to the 48-inch module and its multiples would have to be cut, made to fit, or discarded for some material that could fit the system. This defeats the purpose of modular planning.

In no case must it be necessary to let the module dictate either the space area to be enclosed or the materials to be employed, as this should be determined by the functional and technical requirements. Therefore, the material specification and size should be subordinate to the dimensional requirements of the space and not the dimensional dictates of the module.

Although the single module coefficient is highly disciplined, it does not mean that it cannot be used effectively. The nature of some building elements often dictates the need for rigid modulation. For example, the structural frame; it is most economical and practical to keep framing constant. Therefore, a modular system should allow for the degree of discipline commensurate with the design requirements and the material and construction selected for the building elements. This approach will permit the use of a vast range of materials on the basis of their own limitations. Some material sizes will prove more versatile than others to production in various ranges of material sizes. Modular mean applications, based on common compatible coefficients, will permit a voluntary degree of discipline. Variety in planning of spaces, and of buildings will result. Almost unlimited design flexi-

bility can be provided in a system of modular coordination for industrialized buildings and their precoordinated elements.

You can use the modules limited only by your own ingenuity and imagination, so that you have no restriction of design. Influences related to architectural design and industrialization, organization, space enclosing systems, physical senses, support service systems, the influences of local construction, the locality you work in, transportation, industrial and technical developments, and the stress on science and research are all factors that will effect how you design and express your architecture.

## 4. COMMENTARY

We are changing from the construction of buildings to the assembly of buildings because this is a trend of the period within which we work. We must deal with factory-produced products and components totally fabricated at a factory and assembled at the site. The whole idea is to make our total process of construction more efficient. We seek knowledge so that we can understand. We understand so that we can analyze; with analysis, we can precoordinate. We study building types to find common denominators for basic module selections.

In our own particular practice we found that office buildings lend themselves very well to the multiple of 3, shopping centers to the multiple of 5, schools to a multiple of 3. Then we inject supporting work modules to get your variety and our design control. Now, the one point that I want to make clear is that we are using modules to control our discipline. Actually we are dealing with the space within and the space without. We are dealing with something that is air. So we have complete control over it.

In conclusion, it is not enough to produce a subsystem if you do not provide the quality inplace control as well as the dimension control. You can have all of the coordination and factory-produced products you want, but if they don't reach the site in time to coordinate the job schedules, well then we have the same problem. We must coordinate the hardware as well as the software.

To the architect, open systems are certainly most desirable. For manufacturers they are a little harder to coordinate unless some common system such as A62's is followed by all concerned. Lack of an A62-type control will make closed systems more desirable, at the expense of dynamic architectural expression. Perhaps if we go to closed systems there is the undesirable danger that static architecture will result.

I think that this concludes my formal presentation. The stage is set and the curtian is rising; everybody seems to be ready for industrialization in the seventies. This, to the architect, is very very significant. I certainly hope that each of you in your own discipline will work toward an open system and design flexibility. The market is vast. We can retain continued design quality; we are capable; it will just take teamwork. No man goes his way alone, it is a destiny that makes us brothers.

# ANSI Standards Committee A62—Precoordination of Building Components and Systems History, Structure, and Objectives

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The current A62 Committee is a reactivated form of the original American Standards Association A62 Committee formed in 1939 whose activities were directed toward establishing standards to coordinate the dimensions of building materials and equipment. The work of the original committee, which ended in 1963, produced four standards which set the basis for the modular coordination movement in this country. The need for an active group to provide a focal point for continued effort in modular coordination and with a broader scope brought about the reactivation of A62 with expanded responsibilities and with NBS as sponsor.

The new A62 Standards Committee was formed in October 1966 as a voluntary affiliation with a current membership of five government agencies, 38 industry and professional organizations and universities, 16 corporations and a general interest member. The full committee meets annually and must approve all standards proposed. The Executive Committee is responsible for interim activity.

Stated objectives are:

1. Provide a central forum for component and system coordination.
2. Establish a central clearing house of data and information.
3. Study the problem of achieving precoordination.
4. Define the requirements leading to mutual compatibility of systems.
5. Establish, where essential, performance criteria.
6. Correlate American and International Standards.

Key words: A62 Committee; modular coordination; precoordination.

## 1. HISTORY OF MODULAR CONCEPT ACTIVITIES

The current ANSI Standards Committee A62 is a reactivated form of the original American Standards Association Sectional Committee A62 whose activities from 1939 to 1963 were directed toward establishing standards leading to the adoption and use of modular methods of building design, product manufacture and erection of structures. (See table at end of section, p. —.)

Historically, the modular concept was conceived independently by three individuals in the early 1920's. Frederick G. Heath, for his Masters thesis at the University of Washington, proposed a means of coordinating the dimensions of masonry units, recommending that all such units be based on an 8-inch dimension. Ernest Flagg of New York studied the problem of coordinating dimensions as a means of developing a rational relationship for architectural design.

The third, and best known, was Albert Farwell Bemis, an MIT graduate and wealthy industrialist, who had a deep interest in the development of economical housing. Bemis undertook a prolonged study of modular principles as a means of reducing housing costs and produced a comprehensive three-volume publication in 1936 documenting his exhaustive investigations, just prior to his untimely death in a motor-car accident.

With interest aroused by this work, the Bemis heirs, later in 1936, founded the Modular Service Association and supported it financially through the Bemis Foundation until 1946.

The American Standards Association became interested in the modular concept in 1938 and called an industry conference to explore the possibility of setting up a project in this area. At this meeting, Allan C. Bemis offered financial support and the secretarial and technical services of the Modular Service Association to the project if it were initiated. The industry conference recommended unanimously to ASA that a project on modular coordination be undertaken. Sectional Committee A62, "Coordination of Dimensions of Building Materials and Equipment," was subsequently organized in 1939 with the American Institute of Architects and the Producers' Council as sponsors.

During the next 9 years, A62 produced the only four standards they were to issue prior to the dissolving of the original committee in 1963. These were:

A62.1—1945 "Coordination of Dimensions of Building Materials and Equipment."
A62.2—1945 "Coordination of Masonry."
A62.3—1946 "Standard Sizes of Clay and Concrete Masonry Units."
A62.4—1947 "Clay Flue Linings."
The committee did revise A62.1 in 1957.

Until the end of 1946, the Modular Service Association and A62 activities were supported primarily by Allan Bemis and his associates. On January 1, 1947, these funds were withdrawn, but the Producers' Coun-

cil negotiated a contract between the Office of Technical Services of the Department of Commerce and the Modular Service Association to continue its work for another year.

With the termination of the OTS contract in March 1948, the Modular Service Association was also terminated and this ended the first stage of the development of Modular Coordination.

Following the retirement of the Modular Service Association, the responsibility for further development of Project A62 fell upon the sponsors—at that time, still the American Institute of Architects and the Producers' Council. Neither was able to provide the financial support for the project that had formerly been available, and, as a result, the standards development activity in modular coordination became minimal.

During this period, however, the Producers' Council did sponsor a promotional program and Gordon Lorimer made an extensive series of lectures to architectural and manufacturing groups throughout the country.

The Housing and Home Finance Agency, through Len Haeger as Director of Research, also contributed to the promotion of modular coordination. In addition, HHFA, in January 1949, contracted with the Building Research Advisory Board of the National Academy of Sciences for a survey to determine the factors hindering more general acceptance of the modular principle in design and construction.

BRAB employed Arthur D. Little, Inc., to conduct this survey and submitted its report on June 30, 1949. The first recommendation was:

> Successful further development and promotion of modular coordination in the building industry should aid in providing better homes of lower cost and merits the closest cooperation of all elements of the building industry and the Government. Its accomplishment will require a great and long continued effort. This work has been privately supported for many years, during which substantial progress has been made, but at a very slow rate. Until adequate factual data have been assembled to convince the various sectors of the building industry of the importance of much greater activity than is now in prospect, substantial financial support will need to be provided by the Government if the project is to proceed at a healthy rate.

As so often happens after a study of this type, no action was taken by HHFA on this recommendation.

Other recommendations suggested work to document the savings resulting from modular coordination, providing technical services to assist architects in producing modular drawings, giving aid to manufacturers in developing modular sizes and helping to educate all segments of the construction industry, including the customer.

In 1949, the Joint Committee of the AIA and PC, the cosponsors for A62, called a meeting of industry representatives to discuss means of reactivating modular coordination. As a result of this meeting, industry, principally trade associations, agreed to finance an Office of Secretary for Modular Coordination in the American Institute of Architects.

In May 1950, Bill Demarest was employed for this position, acting, at the same time, as Secretary of A62. M. Edwin Green, FAIA, served as Chairman of A62 from 1946 to 1957. The National Association of Home Builders became the third sponsor of A62 in 1950, and in 1956, the Associated General Contractors became the fourth sponsor.

Bill Demarest's activities were primarily of a promotional nature. He addressed architects' meetings throughout the country, he talked to contractors and building material manufacturers and he collaborated with the Building Research Institute in organizing a research correlation conference on modular coordination which was held in December of 1954. In 1956 Bill Demarest resigned as Secretary for Modular Coordination of the AIA and support for this AIA activity ceased.

In 1957 the Modular Building Standards Association was organized. It was a membership organization and the funds derived from membership dues were used to promote the use of modular measure. Byron Bloomfield was selected as executive director. The new association continued the promotional work begun by Bill Demarest. Its efforts were particularly effective in the area of architect education and dissemination of information. Articles, seminars, symposiums, and text books were generated in quantity and the concept of modular coordination became well known and accepted throughout the construction industry.

While the Modular Building Standards Association assumed sponsorship of Project A62, little or no attention was paid to this phase of modular coordination and no new standards were developed by A62. In February 1963, Mr. Bloomfield, as A62 Secretary, and Mr. C. E. Silling, as A62 Chairman, relayed to ASA the opinion that the A62 Committee had really completed its basic work and requested that the A62 Sectional Commitee be dissolved. Lacking any other support for the committee, the Construction Standards Board complied and A62 was dissolved as a Sectional Committee in the fall of 1963. The Modular Building Standards Association was disbanded soon thereafter because of insufficient membership support.

During the long inactive period of A62, the concept of modular coordination became virtually a household word in the construction industry but there developed almost as many concepts as there were theorists and authors on the subject. In this environment, potential manufacturers of modular items had to rely on their own resources and understanding to design modular products. No basic coordinating standards were written to serve as the common denominator on which to develop modular products. As a result, we now have so-called modular products which are not interchangeable, do not coordinate with other modular products, do not assemble into systems without onsite cutting and fitting, and which, in short, do not provide the advantages of modular coordination their designers and the public anticipated.

This situation together with the knowledge that large components, forming integrated systems, were being developed under the modular concept throughout much of the rest of the world, led the National Bureau of Standards, in the spring of 1965, to evaluate United States activity in this area.

It seemed reasonable to expect that there would soon be a variety of premanufactured building systems available in this country. In the schoolhouse area, progress was well along and was being followed in other areas. Availability of a variety of components—structural, ceiling, wall, floor, partition, mechanical, and other—appeared imminent. NBS felt it would be highly desirable if development of these components could be coordinated so that they would be interchangeable and compatible to form total, prefabricated construction systems. Such coordination would be an extension and refinement of the modular concept and an extension of current industry practice which offers preassembled units.

It was believed that the philosophy of such coordination should not be to develop closed systems, but to establish guidelines for open systems so that all systems, components and parts could be fully interchangeable as far as possible. In addition such an approach should provide for variety of placement and flexibility of design. The intent of such coordination would not be to supplant conventional construction with a stereotyped discipline, but rather to have the economy of preplanned and coordinated components available to the designer when and where they could be utilized. The task appeared to be primarily an engineering task. There were myriad modular theories and interpretations from which a consistent body of standards had to be developed. Such standards could be based on the effective application of modular principles to products. This engineering or application task would certainly not be an easy one, but would have to be achieved if the benefits of modular were to be realized in truly better buildings at less cost.

If there was to be any coordinated application of modular principles in the engineering of building products and systems, it was obvious there had to be an industry-wide organization to establish direction and formulate positions.

With this in mind, John P. Eberhard, then Deputy Director of the Institute for Applied Technology, National Bureau of Standards, wrote to the American Standards Association expressing the Institute's interest in seeing the establishment of a project dealing with the coordination of building components and systems. Mr. Eberhard offered the assistance of NBS in initiating and sponsoring a project in this area if requested.

The ASA Construction Standards Board Executive Committee considered the NBS proposal and voted to request NBS to organize an exploratory committee, consisting of individuals concerned with premanufactured building components, to make a survey to determine the need, interest, and value of such a project, and to submit any recommendations they might have to the Construction Standards Board.

Acting on these instructions, a study committee of some 25 people was organized by NBS, the problem studied, and a report developed. The conclusions of the study committee were:

1. A large number of manufacturers are now producing building components which must be coordinated with other components to be effectively marketed and used. The producers of these components are informally coordinating their products with other manufacturers in small unrelated groups today. However, duplication of effort, diverse and often conflicting solutions, and confusion about where to turn is hampering their effectiveness. It is concluded, therefore, that there is need for ASA national consensus activity in this field.

2. Virtually all producers of building components would welcome establishment of a single, effective coordinating mechanism to deal with the problem of component and system compatibility. It is concluded, therefore, that there is interest in an ASA project in this field.

3. Virtually all members of the study committee agreed that activity under ASA procedure, applying "modular cordination" type concepts to the coordination of building components and systems, is not only desirable but necessary, if real progress is to be made in component system development. It is concluded, therefore, that an ASA project dealing with the application of modular concepts to component coordination would be of value.

4. The subcommittee investigating the performance aspect of component coordination agreed unanimously that there is a definite need for performance standards for building components and systems, and that it would be feasible to develop such standards, although it would be a difficult and complex task. It was concluded, therefore, that the proposed project should have the scope to deal with performance criteria where the functional, as well as dimensional, compatibility of components and systems is found desirable. It should not, however, seek to develop performance criteria except as a last resort, but should rely on other organizations active in this field to provide it with the performance criteria it requires for its coordinating activities.

5. Investigation of modular coordination activity in Europe showed that this activity has resulted in many coordinated components and component systems. The investigation also showed that the worldwide modular activity had broadened considerably in scope from the purely dimensional 4 inch, or 10 centimeter, module and in some countries now includes the development of building systems of component modules. In many countries modular coordination means components coordinated both functionally and dimensionally. It was concluded, therefore, that the proposed ASA project was not in reality a new activity but a natural expansion and growth of the work begun by the A62 project dealing with modular dimensional coordination and should be based thereon.

In light of the data accumulated by the study committee, and the conclusions drawn thereon, the study committee recommended to the Construction Standards Board of ASA that (1) an active Sectional Committee of Project A62 be reestablished so that it could provide a needed focal point for the growing and ever broadening needs of modular coordination of building components and systems; (2) the reactivation of an A62 Sectional Committee be contingent on expanding the A62 scope so that it could deal with the full spectrum of problems posed by modular coordination and not just the dimensional consideration; (3) the reactivation of A62 Sectional Committee be contingent on a complete restructuring, rather than a revival of the old, with new sponsorship and membership reflecting its broadened interests and responsibilities; and (4) the new project have the following objectives:

a. To provide a central forum where all those from diverse and unrelated industries who have a significant interest in the development and/or installation of building components or specific building systems can meet, establish mutual goals, define mutual problems, set machinery in motion to solve these problems and establish guidelines for the orderly development of mutually coordinated building systems from fully compatible building components.

b. To establish a central clearinghouse of data (past, present and future) directly related to coordination of building components and/or building systems which will be available to the committee and to industry for evaluation and research. Initial efforts will provide a background of information to help identify those areas of the problem most urgently needing attention.

c. To study the problem of achieving precoordination of building components with emphasis on modular concepts, especially with respect to compatibility at the interface or area of contact between two or more separate building components to insure minimum field labor or onsite modification.

d. To define the requirements that will lead to mutual compatibility between building systems so that all may integrate together smoothly both during construction and in the performance of their various functions.

e. To establish, where none exists and where considered essential, performance criteria that will provide guidelines for the orderly development of compatible building systems of precoordinated building components.

f. To correlate American and international standards for precoordinated building components and compatible building systems.

These conclusions and recommendations were forwarded to the Construction Standards Board of ASA and on May 3, 1966, the Construction Standards Board, by letter ballot, approved the reactivation of the A62 project under the sponsorship of the National Bureau of Standards with the objectives, as just outlined. Approved title and scope as follows:

Title: A62—Precoordination of Building Components and Systems.

Scope: "The development of a basis for attaining both functional and dimensional compatibility and interchangeability of building components so that they integrate with a minimum of onsite modification, and the establishment of guidelines for coordinating building systems. This activity is limited to the interface requirements of components, or systems, or both."

## 2. ORGANIZATION AND OPERATION

The reactivated A62 Standards Committee was formally organized in October 1966 as a voluntary affiliation with a current membership of five government agencies, 38 industry and professional organizations and universities, 16 corporations, and a general interest member. All participation is voluntary, with the members contributing both their time and the expense of attendings meetings, etc.

A62 operates under a formalized procedure which is available upon request from our secretary, Mr. Russell Smith, to anyone interested. In general, it provides for the full A62 Committee meeting once a year, in the fall, an annual business session. With the exception of the approval of standards, which requires a letter ballot of the full committee, responsibility for interim A62 activity resides in the Executive Committee.

The Executive Committee consists of the A62 Chairman, Vice Chairman-Secretary, both appointed by the sponsor, and the chairmen of the various subcommittees, who are elected annually by the membership. Currently there are four subcommittees responsible for planning and programing activities in each of four program element areas. These are: dimensional coordination, functional coordination, application, and communication. These subcommittees are staffed from members of the full A62 Committee. Additional subcommittees will be established as need arises.

The actual development of standards begins with the establishment of ad hoc technical committees. These committees are approved by the Executive Committee, and may or may not consist of members of the A62 Committee. When a final draft of a proposed standard is developed and approved by the drafting committee, it is submitted to the full A62 Committee by letter ballot for approval. When a favorable consensus of the A62 membership is secured, the standard is then forwarded to the ANSI Construction Standards Board, with the recommendation it be promulgated as an American National Standard.

Sponsorship of the activity is by the Building Research Division of the National Bureau of Standards. As sponsor, the National Bureau of Standards is responsible for providing staff support and has contributed much of the technical assistance necessary to conduct an effective effort.

Operating procedures, established by ANSI for its Standards Committees, are followed. This assures that standards recommended by A62 will be developed under the national consensus procedure required for promulgation of American National Standards.

The new A62 Committee is actively at work. Right after our coffee break, you will hear about the accomplishments to date and this will be followed by a presentation of our future program and recommendations. It is hoped that many of you here who are not yet members but have an interest in the kind of activities that will be undertaken by Standards Committee A62 will join our voluntary group and lend your energy, experience, and cooperation to the development of the needed standards and guidelines for precoordinating building components and systems.

## REFERENCES

Information included in this report was freely abstracted from the following sources:


1. Accomplishments, developments, and need for standards activities in the building industry. Reprinted by the Modular Building Standards Association from the Proceedings of the American Standards Association Eleventh National Conference on Standards, October 1960.
2. Modular dimensioning practices. Published March 1959, by Structural Clay Products Institute.
3. Modular measure works for architects, producers, builders. Published by the Modular Building Standards Association.
4. Summary of current reactivation of A62. Compiled by Russell W. Smith, Jr. as secretary for A62 in preparation for the organizational meeting held October 27, 1966, as USASI Headquarters, 10 East 40th Street, New York, N.Y.
5. Status and Program of USASI Standards Committee A62—"Precoordination of Building Components and Systems" issued February 19, 1969.

## Table.—Chronology of modular concept

| | |
|---|---|
| 921–25 | Early work of Heath, Flagg, Bemis. |
| 936 | Publication of "The Evolving House"—3 volume work of Albert Farwell Bemis. |
| 936 | Modular Service Association founded. |
| 938 | ASA Industry Conference to consider modular project. |
| 939 | A62 Committee "Coordination of Dimensions of Building Materials and Equipment" organized. Sponsored by AIA and Producers' Council. |
| 945 | A62.1 issued. "Coordination of Dimensions of Building Materials and Equipment." |
| 945 | A.62.2 issued. "Coordination of Masonry." |
| 946 | A62.3 issued. "Standard Sizes of Clay and Concrete Masonry Units." |
| 947 | A62.4 issued. "Clay Flue Linings." |
| 947 | Financial support of Bemis Foundation for Modular Service Association and A62 activities withdrawn. |
| 947 | Office of Technical Services of Department of Commerce supported work for a year. |
| 948 | OTS terminated contract. Modular Service Association disbanded. |
| 947–48 | Very limited support by AIA and Producers' Council. Some promotional work by PC and by HHFA for modular coordination principles. |
| 949 | HHFA contracted for study by BRAB to determine factors hindering more general acceptance of modular principles. |
| 1949 | Primary recommendation of BRAB Study. |
| 1949 | Industry finances an Office of Secretary for Modular Coordination in AIA. |
| 1950–56 | Promotional activity by Bill Demarest during the 6 year life of Office of Secretary for Modular Coordination. |
| 1950 | National Association of Home Builders becomes third sponsor of A62. |
| 1956 | Associated General Contractors becomes fourth sponsor of A62. |
| 1956 | Office of Secretary for Modular Coordination closed. |
| 1957 | Modular Building Standards Association organized. A membership organization which also assumed sponsorship of A62. |
| 1957 | Standard A62.1 revised. |
| 1963 | Original A62 dissolved. |
| 1965 | NBS Institute of Applied Technology proposes new activity for component coordination to ASA. |
| 1965 | Study Committee considers need and interest in new ASA project on coordination. |
| 1966 | Study Committee recommends reactivating A62 with new and broader scope which is approved by ASA. |
| 1966 | Reactivated A62 Committee organized as "Precoordination of Building Components and Systems." |

# Accomplishments to Date: A62.7

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**General Services Administration**
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The history of the development of American National Standard A62.7, Basis for the Vertical Dimensioning Coordinated Building Components and Systems, is explored. The technical features of this standard as well as its rationale are examined also.

Key words: A62 Committee; coordinated components; vertical dimensioning.

## 1. INTRODUCTION

Let me begin my discussion by stating that the ANSI Standard Basis for the Vertical Dimensioning of Coordinated Building Components and Systems has been approved by the membership of A62. It has been assigned the number A62.7. Although not yet published, draft copies of it are included in your packet. There are, incidentally, a few typographical errors in the draft.

I had the honor of being the Chairman of the drafting committee which developed the standard, and the other members of the Committee were:

Mr. Kenneth Behr of the Lennox Industries.
Mr. W. D. Page of the American Plywood Association.
Mr. J. W. Glaser of the E. F. Hauserman Co.
Mr. T. W. Redmond of the National Concrete Masonry Association.
Mr. Robert Cowling of the American Institute of Architects.
Mr. Eugene Bowles of the New York Telephone Co.
Mr. Henry Omson of the Gypsum Association.

I feel that this represented a very well-rounded group of industry, consumer and professional interest. In addition, I must mention that this was all done with the able guidance of Mr. Gaston, Chairman of A62, and Mr. Smith, the Secretary.

## 2. BACKGROUND

When the drafting committee was assigned the task of developing a Standard Basis for Vertical Dimensioning, it became immediately evident that we faced two situations:

First—a multiplicity of story heights, ceiling heights, and other vertical heights used in design or needed to suit in-field conditions.

Second (as should be evident from what has been discussed here previously)—the desirability of keeping the number of standard sizes of factory-built components to a minimum, and consistent with each other, in order to achieve the maximum benefit to be derived from industrialization.

Thus, the task of the drafting committee was to "wed" these two situations—in other words, to provide a standard which would allow for prefabrication of components and systems in a minimum number of sizes in such a way as to allow a maximum number of design and dimensioning alternatives.

How did we go about this?

First of all, we had to recognize the fact that for many common building components, prevailing industry practice had, in fact, already established standard dimensions. For example, the 4- by 8-foot sheet of plywood and wallboard, and many of the other components which Mr. Geiger discussed yesterday. Likewise, prevailing practice among architects had also tended to standardize upon certain heights used consistently in design, partly because of de facto standardization in industry, and partly for anthropometric reasons, in other words to fit the human figure. For example, the 6-foot-8-inch door and the 8-foot ceiling are pretty well recognized as being standard for residential construction.

Second, we had to recognize the multiplicity of design objectives. The standard would have to be usable for all types of buildings and with all types of construction: residential construction, office buildings, hospitals; concrete frame, wood frame, steel frame, wall-bearing; buildings with suspended ceilings and without them; buildings with elevated floor systems; buildings where space for mechanical and electrical services in the floor-ceiling sandwich would be crictical to the design; and buildings where the ultimate objective might be to squeeze as much usable space as possible into as little vertical height as possible.

We also had to recognize the need for flexibility in design. We had to recognize the desirability in some cases of not using standard size components and provide means for integrating these into an otherwise dimensionally coordinated design in such a way as to optimize the use of components which could benefit from standard dimensions. Floor fill, for example, can rarely be used economically in thicknesses which are a multiple of 4 inches—yet floor fill serves a necessary purpose in many designs which can benefit from the use of dimensionally standardized components. Likewise, the depth of structural framing must also frequently deviate from 4-inch incremental dimensions to assure economical design.

Finally, and perhaps most important of all, we had to recognize that this standard would undoubtedly establish ground rules for other subsequent standards which would follow, and would set the pattern for industry in gearing up for prefabrication of building components on an ever-increasing scale. So to a degree, we had to let our imaginations run wild in order to consider possible future innovation.

Where did we look for guidance?

Recognizing that any dimensional standard must be thought of in terms of three dimensons (and in fact of the fourth dimension of time), and that verticality is only part of the total dimensioning discipline, we first looked to the already established standard for Horizontal Dimensioning, A62.5. The two standards obviously had to compliment each other, and to a degree A62.5 had already established the ground rules for us. However, the practical problem of laying out a series of components in plan and that of stacking them are very different.

We also looked for guidance to the existing international standards—in particular those of the Scandinavian countries. We looked quite deeply into these European developments, and profited from the difficulties they were encountering as well as the advances they had made.

## 3. THE STANDARD

Now that you have the background, I would like briefly to discuss the standard itself. Since the standard is available, and since I am sure that many of you are familiar with it anyway, I will not bore you with a detailed description, however, here are the highlights.

First, the standard establishes a multimodule of four modules (16 inches) as the basic increment of vertical dimensioning.

Second, the standard establishes preferred dimensions for story heights, ceiling heights, floor-ceiling-sandwich thicknesses, and other distances between coordinating interfaces separating vertical components.

The term "preferred dimension" needs to be clarified. This does not mean that you must have a ceiling height, for example, that is a multiple of 16 inches in order to have a dimensionally coordinated design. The standard does, however, establish a definite order of preference for the vertical dimensions of components and spaces based upon the 16-inch multimodule, and/or combinations of smaller modular components, in order to permit maximum benefit from a minimum number of component sizes.

The multimodule of 16 inches (see fig. 1) is intended to be used to coordinate all vertical dimensions which exceed 20 modules (6 feet 8 inch). For smaller components a series of preferred dimensions, starting with one module (4 inches), have been selected which will, in some combination, provide one module flexibility, and a minimum number of them (no more than 3) will in various combinations add up to 20 modules, and provide 2 module flexibility for everything above 20 modules. One module flexibility can be achieved by adding one more component.

For components larger than 20 modules in height, the preferred dimensions generally are established in 4 module (multimodule 16 inch) increments: 24 modules, 28, 32, 36, and so on.

Figure 2 is a graphic representation of the application of these dimensions.

In general, for those dimensions which normally exceed 20 modules, the preferred dimensions are selected in 4 module increments (there are some exceptions); however it is always possible to achieve 1 module flexibility by combining smaller components.

In general, for those dimensions which normally are less than 20 modules, the preferred dimensions are selected in 2 module increments (there are also some exceptions to this), and even multiples of the basic module (4 inches) are always given second preference.

No preferred dimension has been established for the thickness of finished floor for reasons discussed earlier. However, in those cases where there is a suspended ceiling, the thickness of the finished floor would be deducted from the preferred dimension for the ceiling space to assure that the preferred floor-ceiling-sandwich thickness is maintained.

Of course, in cases where there is neither a suspended ceiling or a floor fill, the floor-ceiling-sandwich and the structural floor system thickness (C. & E.) would coincide.

Also, the means of integrating custom dimensioned components into an otherwise dimensionally coordinated design is provided. For example, in designs where there is floor fill and structural framing which are of custom dimension, and where there is a suspended ceiling, the ceiling space (F) would be selected so that a preferred dimension would be achieved for the floor-ceiling-sandwich. By doing this consistently at each story, it would be still possible to use a minimum number of repetitive sizes of exterior and interior components which lend themselves to prefabrication.

## 4. CONCLUSION

The standard basis for the Vertical Dimensioning of Coordinated Building Components and Systems together with its companion standards, obviously does not provide a cure-all which will immediately solve all problems in so far as assuring complete integration of standard-sized prefabricated components into a multiplicity of individual building design objectives. These standards are not going to meet every single need nor will they be a substitute for design ingenuity on the part of the architect. However, I do believe that they will prove to be useful tools as guidelines for both the architects who design buildings, and the producers who manufacture the materials, components, and systems which go into them, in providing an orderly dimensional discipline which is so necessary if industrialization of the building process is to meet future building needs in the United States. In the last analysis, their validity will be determined by how architects and fabricators use them.

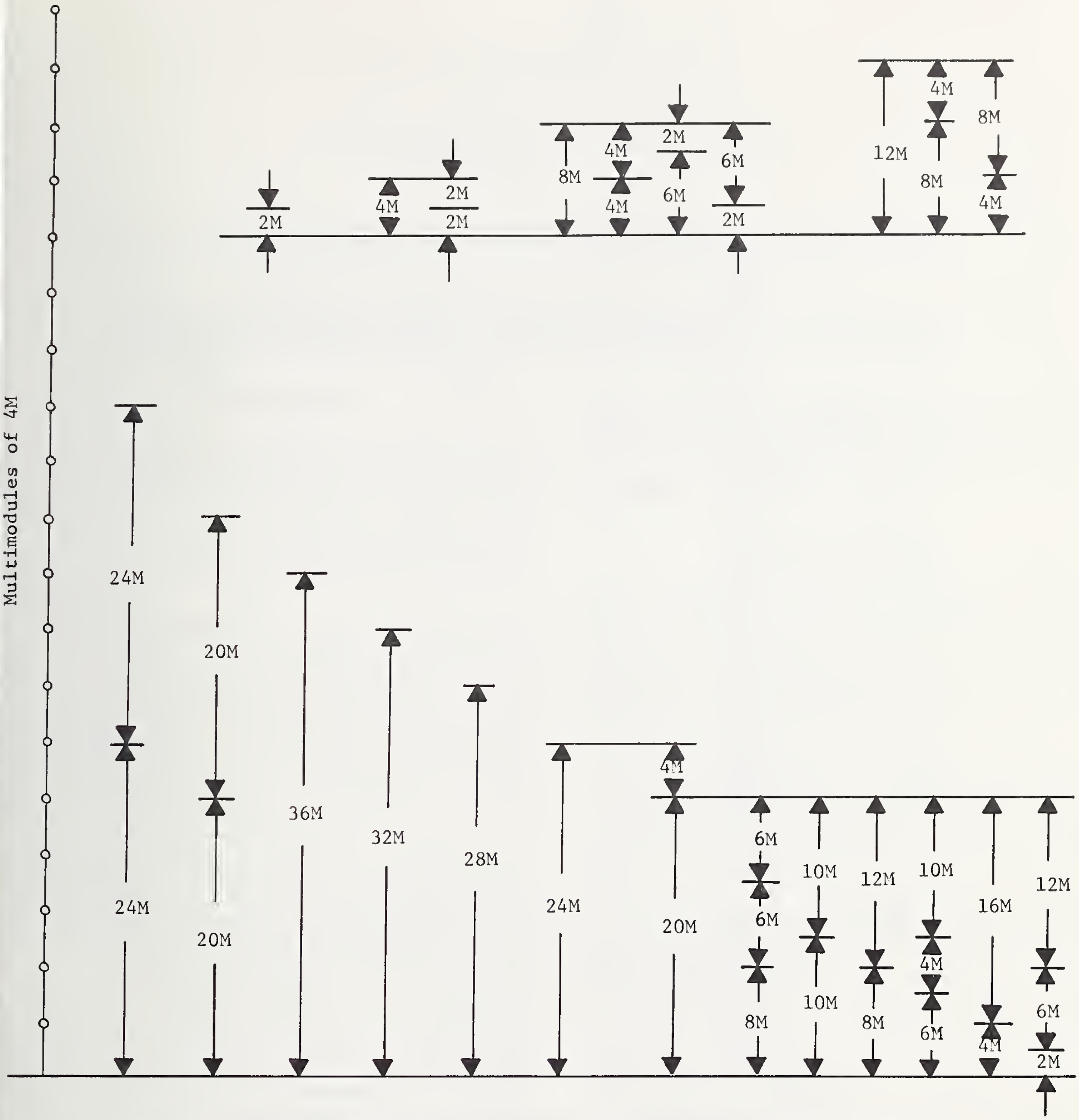


FIGURE 1.—*Relationship of various component and preferred dimensions and verticle multimodule.*

A- Story Height
B- Ceiling Height
C- Floor Ceiling Sandwich Thickness
D- Structural Column Height
E- Structural Floor System Thickness
F- Ceiling Space Dimension
G- Thickness of Finished Floor

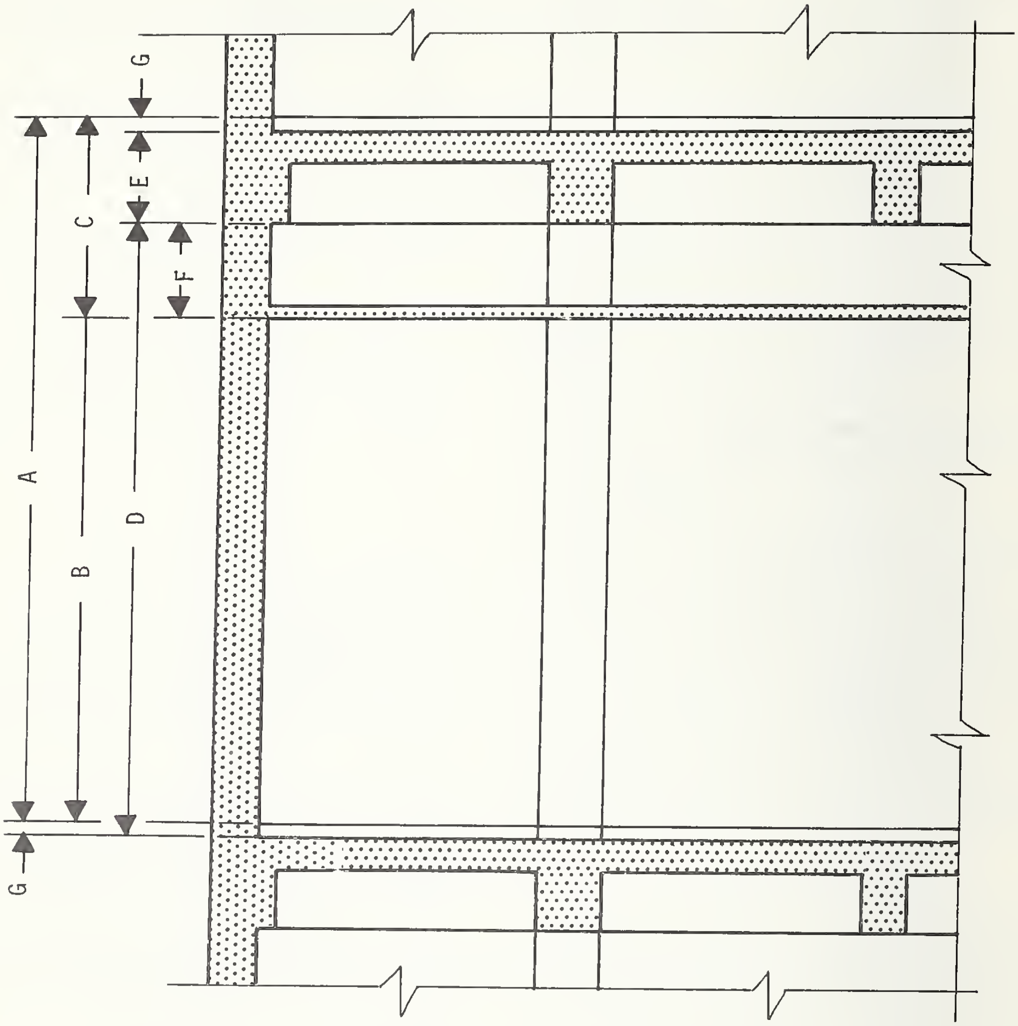


FIGURE. 2—*Graphic representation of application of preferred dimensions.*

# Accomplishments to Date: A62.5

## A62.5 Committee Commentary [1]

The concepts of dimensional coordination based on the module and the numerical relationships which must be dealt with are reviewed in detail. The factors that were reconciled and the use of these concepts in developing the American National Standard A62.5, Basis for the Horizontal Dimensioning of Coordinated Building Components and Systems, are reviewed.

Key words: A62 Committee; dimensional coordination; horizontal dimensioning; numerical relationships.

## 1. INTRODUCTION

Modular coordination concepts have received wide acceptance in the United States for masonry and certain other construction. The concept also is used in various sections of the country by individual architectural firms. However, in general, the design and manufacturing segment of the construction industry has not realized the potential offered by modular coordination.

Recently, developments in systems building have rekindled the need for, and interest in, modular coordination. Current interest and discussion is centered around an increased emphasis on industrialization of the building industry. It seems almost axiomatic that if industrialization is to be attained on a broad scale, then the discipline provided by a fully developed and widely accepted dimensional coordination is mandatory.

It should be recognized, however, that the dimensions presented in this standard are intended primarily for use in the overall modular concept under development by ANSI A62. They are not intended to be applied rigidly to every facet of construction.

## 2. SCOPE

The task of this committee was to prepare a standard for an overall planning module that would provide for a layout grid and for an interrelated set of coordinating dimensions for the components of buildings. It is anticipated that the standard will be applicable to most premanufactured building components or subassemblies and component assemblies. In general, these components range from door and window subassemblies to fully integrated building systems. Most components or systems are produced in a number of different sizes to meet a variety of functional needs. Manufacturers establish the size range for a given product (component or system) based on some orderly relationship between sizes. However, there often is no interrelationship with similar products of other manufacturers.

The establishment of a dimensional relationship in building systems and components will provide for the coordination of systems with each other and provide the necessary flexibility and interchangeability of components.

## 3. DEFINITIONS

Words which are defined are familiar in usage but in this standard they provide a language to better describe the application of the major systems planning and coordination module for building systems and components. Each definition given is descriptive of the use of the word in this standard, although it may not be complete for the scope of the word.

## 4. ESTABLISHMENT OF SYSTEMS MODULE

The dimensions in this standard attempt to meet the major requirements for a system suitable to the U.S. building industry. These requirements were considered to be:

1. That any system of preferred component sizes be based on whole number multiples of the (4 inch) basic module established as an American National Standard in 1957.
2. That combinations of the sizes selected lend themselves to meeting random demands through "additive" combinations.
3. That the sizes selected form a systematic series of numerical relationships.
4. That all sizes selected be factors of a single systems module (SM) and that this systems module be small enough to serve for coordinating building systems with one another.
5. That all series of sizes selected include most major component sizes now in use in the United States., and parallel existing series as closely as possible.

The basis for the committee's choice of a 60-M systems module and its series of preferred sizes is based on numerical relationships that can be categorized under three headings; Additivity, Relationship of Series, and Multiple Relationships. These are discussed in detail as follows:

[1] Mr. Burr Bennett, the Chairman of the Technical Committee which developed A62.5, was out of the country and unable to report at the time of the Conference. This report by the Committee is included in the interest of completeness in relation to th subject matter of the Conference.

## 4.1 Additivity

Additivity refers to the relationship of components (observed by M. Jean-Pierre Paquet in 1943) which is such that three carefuly selected modular component dimensions may be combined to provide any modular dimension above some critical dimension. For example, lengths of 1, 2, and 5 basic modules in some combination will provide all modular lengths above 1 module, in 1-module increments, while lengths of 2, 4, and 10 will provide every even-numbered dimension in 2-module increments; 4, 8, and 20 in 4-module increments, etc.

In some buildings the components often can be arranged in a uniform manner. These include beams and columns, components of floor and ceiling systems, partitions, and curtain walls. Such components adapt to uniform dimensioning and repetitive use.

However, the situations where space can be uniformly divided in a repetitive manner may be limited by functional needs.

Fortunately a range of component sizes need not preclude use of the same components for a variety of random dimensions. This is especially true with a system based on a 4-inch basic module. In practice, this requires that manufacturers choose as few sizes as possible to provide an interrelated numerical series for symmetrical use, which also may be used, in some combination, to provide any modular (multiple of 4 inches) dimension required. Thus, "additivity" is an essential quality in choosing preferred sizes.

With the additivity concept, it is possible to choose two sizes which when used side by side will make up any 4-inch increment over a critical dimension. The critical dimension may be found by the simple formula: $N = (a\text{–}1)\ (b\text{–}1)$; where $N$ is the critical dimension (in modules) and $a$ and $b$ are sizes of components in modules. For one module flexibility, the sizes chosen must have no common factor. The formula can be applied to two sizes such as 5 M and 6 M or 4 M and 5 M but not to 6 M and 8 M (common factor 2). In such cases the sizes must be doubled or tripled, etc., until there is no common factor and the answer will of course be expressed in these double or triple size modules.

The two sizes need not be consecutive. The formula $N = (a\text{–}1)\ (b\text{–}1)$ will show that 5 M and 12 M will give 4-inch flexibility after 44 M. If two sizes with a common factor are chosen they can never give 4-inch flexibility. For example, sizes of 6 M and 10 M have a common factor of 2 and in order to be able to use the formula it would be necessary to consider that the sizes were 3 M and 5 M respectively but with M now equal to 8-inches.

$$N = (a\text{–}1)\,(b\text{–}1) = (3\text{–}1)\,(5\text{–}1)\ \mathrm{M} = 2 \times 4\ \mathrm{M} = 8\ \mathrm{M}$$

As M = 8 inches in this particular example, a component made in the two sizes 6 M (2 feet) and 10 M (40 inches) would provide 8 inch flexibility over 5 feet 4 inches.

For a practical example, assume that a manufacturer wishes to standardize the width of kitchen cabinets. The functional requirements for the width from the point of view of space for storage of household goods and a convenient size of door is approximately 2 feet. Therefore, try 5 M (1 foot 8 inches) with 6 M (2 feet).

$$\begin{aligned} N &= (a\text{–}1)\,(b\text{–}1) \\ &= (5\text{–}1)\,(6\text{–}1) \\ &= 4 \times 5\ \mathrm{M} = 20\ \mathrm{M} = (6\ \text{ft. } 8\ \text{in.}) \end{aligned}$$

This is a reasonable dimension at which to achieve 4-inch flexibility because there will not be a great proportion of room spaces less than 6 feet 8 inches.

## 4.2 Relationship of Series

The selection of sizes to form a systematic series of numerical relationships must also satisfy a requirement that the next larger size in a series always be some useful multiple of the smaller size(s). Also it is desirable that a size in any one series be divisible by the smaller size(s) found in other series. Possibilities for useful numerical series include a Fibonacci series in which the next larger number is always the sum of the preceding two smaller, geometric doubling or tripling series, and arithmetic series with intervals of 2, 3, 5 etc. The more important of these numerical relationships are shown in figure 1.

While it is recognized that a series of preferred modular sizes cannot be based exclusively on theoretical relationships it can be seen that certain numbers are repeated in more than one series. It appears that a useful series can be selected which will include such repetitive numbers. As noted in the lower portion of figure 1 the sizes 1, 2, 3, 5, 8, 21, and 30 appear most frequently in the series listed.

## 4.3 Common Multiple Relationships

In addition to usual numerical relationships, the modular concept requires that the sizes within series be developed from some common multiples. After some deliberation the following numbers were assumed for these common multiples; 1, 2, 3, and 5. To examine this attribute, in figure 2 a tripling series of 1 and 5 is formed reading diagonally from left to right, and a doubling series reading diagonally from right to left. The series are extended to larger sizes than were used in figure 1.

This table includes every size in figure 1 that appears in two or more series except for 21, which is discarded because its use as a functional component dimension seems awkward.

In the modular concept, the largest size selected in a series is called the Systems Module. To be suitable, a systems module should be divisible by all the assumed common multiples 1, 2, 3, and 5. In this category, as shown in figure 2, a Systems Module of 30, 60, 90, or 120 could be selected.

These possible systems modules have the following factors:

| | | Total |
|---|---|---|
| (30) | 1, 2, 3, 5, 6, 10, 15, 30 | 8 |
| (60) | 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30, 60 | 12 |
| (90) | 1, 2, 3, 5, 6, 9, 10, 15, 18, 30, 45, 90 | 12 |
| (120) | 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 24, 30, 40, 60, 120 | 16 |

## RELATED SERIES

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A. FIBONACCI SERIES | 1 | 2 | 3 | | 5 | | | 8 | | | | | 13 | | | | | | | | 21 | | | | | | | | | |
| B. GEOMETRIC DOUBLING | 1 | 2 | | 4 | | | | 8 | | | | | | | | 16 | | | | | | | | | | | | | | |
| C. GEOMETRIC TRIPLING | 1 | | 3 | | | | | | 9 | | | | | | | | | | | | | | | | | | 27 | | | |
| D. ARITHMETIC INTERVAL OF 2 | | 2 | | 4 | | 6 | | 8 | | 10 | | 12 | | 14 | | 16 | | 18 | | 20 | | 22 | | 24 | | 26 | | 28 | | 30 |
| E. ARITHMETIC INTERVAL OF 3 | | | 3 | | | 6 | | | 9 | | | 12 | | | 15 | | | 18 | | | 21 | | | 24 | | | 27 | | | 30 |
| F. ARITHMETIC INTERVAL OF 5 | | | | | 5 | | | | | 10 | | | | | 15 | | | | | 20 | | | | | 25 | | | | | 30 |
| APPEARS IN 3 SERIES | 1 | 2 | 3 | | | | | 8 | | | | | | | | | | | | | | | | | | | | | | 30 |
| APPEARS IN 2 SERIES | 1 | 2 | 3 | 4 | 5 | 6 | | 8 | 9 | 10 | | 12 | | | 15 | 16 | | 18 | | 20 | 21 | | | 24 | | | 27 | | | 30 |
| APPEARS IN (A) AND ONE OTHER SERIES | 1 | 2 | 3 | | 5 | | | 8 | | | | | | | | | | | | | 21 | | | | | | | | | |

Figure 1

From this analysis it appears that the 120 module offers the greatest flexibility as a systems module from the standpoint of the number of factors. However, from the standpoint of being small enough to serve as a systems module for coordinating building planning, 120 M (40 ft.) may be too large for general use. If it is discarded for this reason, the choice drops to either the 60 or the 90 module series. Both are equal in the number of factors and equal in the number of times (12) that the multiples 2, 3, and 5 can be divided into the numbers of the series.

After an analysis of all requirements, the committee chose 60 M (20 ft.) as the systems module. The factors 2, 3, 4, 5, 6, 10, 12, 15, 20, and 30 modules offer preferred sizes from which to select dimensions for components.

$\underline{1}$

$\underline{2}$ $\underline{5}$ $\underline{3}$

$\underline{4}$ $\underline{10}$ $\underline{6}$ $\underline{15}$ $\underline{9}$

$\underline{8}$ $\underline{20}$ $\underline{12}$ $\underline{30}$ $\underline{18}$ 45 $\underline{27}$

$\underline{16}$ 40 $\underline{24}$ 60 36 90 54 135 81

32 80 48 120 72 180* 108 270* 162* 405* 243*

64 160* 96 240* 144 360* 216* 540* 324* 810* 486* 1215* 729*

* DENOTES NUMBERS OVER 150 MODULES (50 FEET) CONSIDERED AS BEING TOO LARGE FOR A USEFUL SYSTEMS MODULE.

— DENOTES NUMBERS APPEARING IN FIG.—1

Figure 2

Of the numbers 1, 2, 3, 5, and 8 appearing in the most series in figure 1, all appear in the 60 M series except the number 8. However, 8 M dimension is attainable by doubling 4, and it can be coordinated into the system at every other approved 12 M dimension.

Although eliminated from the standard, the 9, 18, and 90 sizes of the 90 M system have value in terms of current usage. Fortunately, this usage can continue since these sizes can be realized from composites of the 60 M dimensions. Also two 90 M units are compatible with three 60 M units.

## 5. COMPATIBILITY WITH EXISTING COMPONENT SIZES

No system of dimensioning based solely on a series of simplifying assumptions can be successful unless it relates to the functional sizes in use. The numbers in the 60-M system correspond to many functional component sizes in wide use in the United States.

Examining the numbers in the 60-M system:

a. M, 2 M and 4 M (4, 8, and 16 inches) are in wide use as masonry dimensions.

b. 3 M (12 inch) is established in many materials, particularly structural framing.

c. 5 M (20 inch) is in limited use as a partition and ceiling component dimension.

d. 6 M (24 inch) is in wide use.

e. 10 M (40 inch) has some current use in partition and other component systems.

f. 12 M (48 inch) is recognized as probably "the" most prevalent component dimension.

g. 15 M (60 inch) is in wide use as a planning and component module.

h. 20 M (6 feet 8 inch) has use in vertical dimensions of components.

i. 30 M (10 feet) is used for structural and curtain wall dimensions.

j. 60 M (20 feet) is large enough to serve as the systems module yet small enough to allow its multiple use.

## 6. SUMMARY

The proposed standard provides coordinating dimensions for components that are related to an overall horizontal planning grid or systems module. Other committees are developing comparable standards for vertical modular coordination and for the critical problems associated with placement of components on the modular grid. Effective use of all established dimensions must, in many cases, await the development of such standards.

Use of the dimensional coordination set forth in this standard for components manufactured in accordance with it requires judgment rather than blind adherence. For example, many components can observe a common basic module if they do so only in the plane with which they are concerned, but should ignore thickness of components that interrelate in the third dimension until additional standards covering this aspect are developed.

It is hoped that the range of sizes proposed is adaptable to most building components. If these components, though linear or planar in use, can be designed with other modular perpendicular intersecting components in mind, then the desired interchangeability of components of various manufacture can be achieved.

This interchangeability should benefit both the architect and the manufacturer in assuring that any given component would assembly correctly with others. It should greatly reduce the shop drawing burden on the manufacturer and architect and reduce field measuring and coordination on the part of the contractor.

This standard has been designed to provide a broad basis for a dimensional discipline that will aid in the development of industrialized systems to reduce costs and improve performance of structures. The committee hopes it will be useful in this respect.

# Future Program and Recommendations

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This paper presents the program adopted by the Executive Committee of the A62 Standards Committee for conducting the work relative to the development of the standards necessary to industrialize the U.S. building process. Such standards will establish a basis for both functional and dimensional compatibility and interchangeability of building components so that they integrate with a minimum of onsite modification and the establishment of guidelines for coordinating building systems.

Key words: A62 Committee; dimensional, and functional compatibility, interchangeability.

## 1. INTRODUCTION

Jack Gaston has just described the history and objectives of A62. I should now like to examine briefly the conditions in the United States which make the A62 effort important and then go on to describe how A62 is meeting responsibilities thrust upon it. The conditions I refer to are, of course, related to a shortage of buildings, particularly housing.

Many authorities have established that the production of buildings in the United States must be substantially increased in the next decade. This increased production is needed to meet population and economic expansion, and to replace existing buildings, which are becoming obsolete at an accelerating pace.

To better understand the building shortage in the United States it is important to point out that a significant portion of this shortage is unique in world history. That portion of the shortage that relates to replacing existing building is a shortage born primarily of affluency, rather than physical shortage of the buildings themselves.

Almost without our knowing it, the rapid, and ever-accelerating growth of our dynamic nation has changed requirements for existing buildings at a rate that exceeds our ability to remodel, rehabilitate, or to tear down and replace such existing buildings. Particularly in the cities, changing and growing communities are making buildings obsolete and necessitating their replacement, where such buildings were adequate solutions to their community needs just a few years ago.

As a result, we are faced with a very real, and very serious shortage of buildings. This shortage consists, in part, of buildings that no longer adequately meet user requirements. That portion of our shortage due to the unacceptability of existing buildings is a direct result of a building technology which produces static solutions that cannot respond to the ever-changing user requirements of a dynamic culture. What happens is that utility is lost due to unplanned obsolescence.

The lifespan of our static building solution, and the lifespan of user requirements for buildings are seriously out of phase.

## 2. INDUSTRIALIZATION—A SOLUTION

If we can industrialize the assembly process of buildings, so that building products already mass produced become finished parts, not pieces, we can increase capacity to meet our needs in the next decade. But, industrialization alone will not necessarily produce buildings more in phase with user requirements. It is quite possible to mass produce buildings industrially which have an unplanned obsolescence rate higher than buildings produced by current practices.

If we industrialize just to achieve volume, we may find in the decade from 1980 to 1990 that an ever-accelerating unplanned obsolescence rate again forces us to double, or even triple, the production rate. Static solutions, however produced, breed unplanned obsolescence when requirements are dynamic.

Thus, solving the Nation's building problem requires a short-term solution to produce buildings to meet current needs and to replace existing buildings already obsolete.

It also requires a long-term solution to produce a building technology capable to adjusting to a wide range of user requirements both foreseen and unforeseen.

The A62 role, an essential and irreplaceable element in both long- and short-term solutions, is to increase substantially the industrialization of the process by which buildings are produced. If the long-term solution is to be achieved, this industrialization must be carefully planned, thoroughly coordinated, and programed to provide a coherent, nationwide system with maximum flexibility.

This is precisely the role and function that A62 was organized to fulfill. The program of basic coordination, which A62 is now implementing, is providing the U.S. building industry an underlying system of basic industrial standards that will increase immeasurably its productivity and its flexibility to meet change.

Considering the importance of A62 as the recognized forum for building industry coordination, and the essential function it is performing, it might be well to

make a brief review of the status and composition of the A62 Committee. First, let us examine what A62 is, and is not.

A62 is a national standards committee. As such, it is an independent, autonomous group consisting, at the present time, of some 63 members. The membership represents a cross-section of the building industry and includes trade associations, professional associations, corporations, government agencies, and members-at-large. Virtually every major organization and interest in the conventional building industry is represented. The cumulative total of experience and construction industry knowledge is truly staggering.

The American National Standards Institute, Inc., has recognized that the A62 Standards Committee represents a national consensus of the building industry in the area of standards which pertain to the functional and dimensional compatibility of building components and systems. This means that, ANSI will recognize A62 consensus as national consensus, within its area, and barring unusual complications, will promulgate standards developed by A62 as American National Standards. To aid this approval, A62 follows ANSI procedures.

The National Bureau of Standards sponsors A62. This means that NBS furnishes the technical and administrative staff assistance necessary for A62 to transact its business. In addition, NBS furnishes technical support. This supporting technical staff keeps abreast of the state-of-the-art of coordination on a worldwide basis, develops programs responsive to USA coordination needs, and recommends programs and standards to A62.

Now a word about the relationship of NBS to the A62 Committee.

## 3. NBS RELATIONSHIP

The NBS program in support of the A62 effort is essentially a pilot project. It was authorized by John Eberhard, former Director of the Institute for Applied Technology, in the spring of 1966 to test the effectiveness of NBS sponsorship as a catalyst in a total industry standardization effort. Its objective was increased productivity in the building industry.

In addition, another objective of the pilot program was to test the feasibility of applying advanced technology on a total industry scale, through the medium of national standardization.

It was, and is, the purpose of this pilot project to help develop the systems technology, and its application, required for the industrialization of buildings.

The product of the NBS support effort is passed on to A62 as a recommendation only. Such recommendations are rejected, accepted, or thoroughly reworked, at the option of the A62 membership.

In the consensus procedure of A62, NBS is one of 63 members and has one vote like the other 62. Thus, A62 is a Standards Committee of the U.S. building industry.

A62 has been effective because it is a balanced cooperative effort of all interests. Regardless of its need for increased financial support, it should not be dominated by any interest group, public, or private. Its value lies in its ability to operate impartially, free from any political, industrial, or professional pressures.

As A62 grows in importance, as it most assuredly will, balanced support and freedom to remain impartial must be maintained at all costs.

## 4. THE A62 PROGRAM

Let us now take a look at the A62 program. I feel you will share with me and the officers and members of A62 the belief that this concept of precoordination offers a practical, workable approach to the solution of today's building dilemma.

The keystone of A62's program is the scope assigned it by ANSI. For standards falling within this scope, ANSI recognizes A62 as being the cognizant national consensus group. Figure 1 shows the scope assigned to A62 by the Construction Standards Board of ANSI.

This scope tells us a great deal about A62 coordination and its philosophy "Development of a basis," shows concern with the underlying system.

"Both functional and dimensional," indicates an intent to do the whole job of coordination and not just part.

"Compatibility and interchangeability" implies flexibility. For with compatibility and interchangeability between like and unlike components, of all types and of all designs, the possibilities for flexibility are infinite. "Guidelines" shows that the product of A62 is unique. It is not a standard in any usual sense of the word, but is rather a guideline, or productivity recommendation, which is unique in U.S. Standardization and perhaps in the world.

Part of this uniqueness comes from the word "interface," which limits A62 coordination to the relationships between things . . . their interface . . . and not to the things themselves. We would not standardize a window, or a rough opening, but would instead standardize the imaginary boundary between them.

Thus, the A62 program is formulated to achieve coordination at the interface of building components, of components and systems, and of systems, so that both functional and dimensional compatibility and interchangeability are achieved.

For ease of handling coordination problems, three distinct areas of concern have been identified and established as separate program elements. These elements are:

1. Establishing a basis for dimensional coordination.
2. Establishing a basis for functional coordination.
3. Establishing a basis for communication coordination.

You will recognize the similarity of these program elements to the subject areas of this conference . . . a precoordinated coincidence.

Within each of these program elements, three phases of standards development are programed. These are shown in figure 2. In Phase I, those standards which establish the framework applied to future coordination

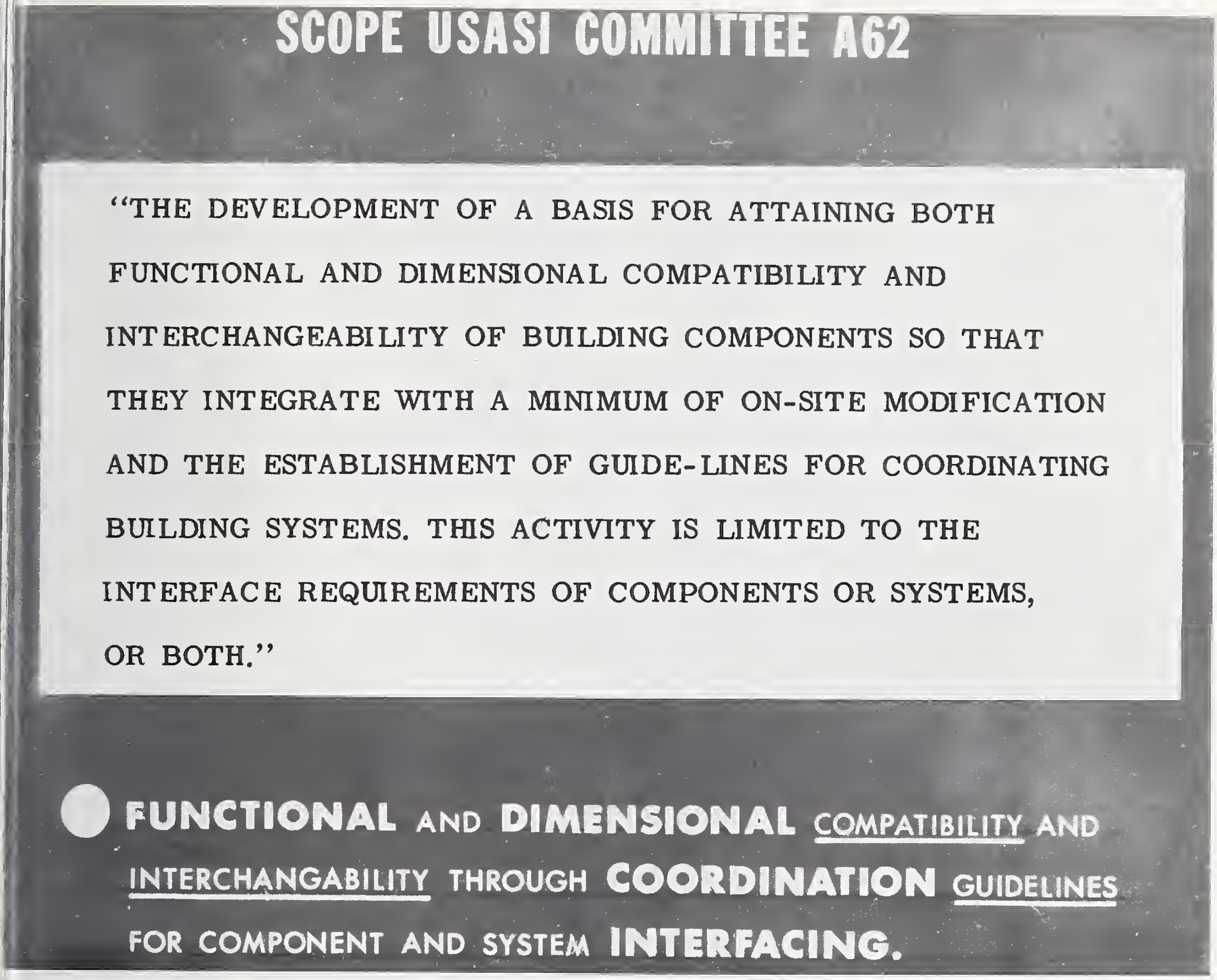


Figure 1.—*Scope—A62.*

are developed. These standards are few in number, but their development is essential to any further coordination progress. Such standards must be developed in some fixed order, one being a prerequisite of the next.

Phase II calls for the development of standards by A62 that apply the basic standards of Phase I to specific components and systems. In this phase, A62 will have to initiate projects to see that coordination is applied to all key components and systems. Phase II is simply an expediency until Phase III is operational.

Phase III calls for certifying standards developed by others as conforming to A62 principle. Essentially, in this phase, the basis of A62 coordination will be established and fully recognized, and guidelines for most key components will have been written. Manufacturers and industry groups representing other components will voluntarily develop and submit standards for acceptance and promulgation by A62 as a means of securing endorsement of their components and systems as conforming to the A62 system of coordination. The committee's activity in this phase will be simply one of review.

Figure 3 shows the distribution of the A62 effort by program element. At the present time the majority of effort is devoted to dimensional coordination. Functional coordination occupies less than 10 percent of the total effort and communications coordination even less.

The slope of the curves is not intended to predict the expansion rate, but only to indicate that total activity will expand. Of the total A62 activity, it is predicted that in 1975 there will be approximately equal distribution among the three program elements. The dotted line bounding the communication program element indicates the open-ended growth potential in communication coordination due to the application of computer technology.

Figure 4 shows the distribution of the A62 effort by program phase. You will note that the boundary envelope again has a slope intended to show an expanding effort and not necessarily the rate of expansion.

At present, most of the effort is directed to Phase I activity establishing a basis for coordination. Phase II comprises a small portion of the present total

**A62 PROGRAM**

| ELEMENTS | PHASES | | |
|---|---|---|---|
| | I - Basis for Coordination | II - Application of Basis | III - Certification of Conformance |
| 1. Dimensional | 8 Plus Standards | ? | ? |
| 2. Functional | 6 Plus Standards | ? | ? |
| 3. Communication | 5 Plus Standards | ? | ? |

FIGURE 2.—*A62 Program.*

activity. Principally this is directed toward determining priority, and logical sequence, for applying the basis of coordination to key components and systems.

The Phase III activity is limited at present to a pilot project with the Steel Door Institute. A technical committee of SDI approved by A62, is currently developing a proposed standard for steel doors and frames conforming to A62 dimensional coordination. This is an important project and will develop criteria for all Phase III standards in the future. Several industry groups have expressed interest in establishing projects for other product and component groups. When enough industries initiate Phase III projects, Phase II can be eliminated.

### 5. DIMENSIONAL PROGRAM ELEMENT

Establishing a system for dimensional coordination requires a comprehensive set of standards. Without regard to the many technical and industrial problems which must be solved and compromised, I will describe the A62 system in terms of its standards.

These standards, as identified and programed by A62, are shown in figure 5 arranged in a hierarchy according to development sequence, each level being a prerequisite for the next.

No work in dimensional coordination is possible without a basis for measurement and a uniform unit of measure. Fortunately, the concept of the basic module (4 inches in the United States and Canada, and 10 c. in the rest of the world) was established as an ANSI standard two decades ago and is available to us.

Unfortunately, an agreed upon increment of measure is not enough, in itself, to serve as the basis for an industrialized system of interchangeable parts. You must also have standards for series or progressions of sizes. Such size series are a keystone of industrial production.

A theoretical system of standard building component sizes would look something like figure 6 It shows a slide developed to illustrate the modular concept some 20 years ago. Unfortunately, no one was able to do anything about assigning real numbers to the concept.

For maximum usefulness, size series are related so that each larger size is always a combination of smaller size or sizes. The more combinations possible, the more useful the series. The standard for horizontal dimensioning, A62.5, now an ANSI Standard, contains a series of 12 progressive sizes. Every component in the series has a numerical ratio of 2, 3, 4, or 5 to other sizes.

Figure 7 shows values assigned to horizontal component dimensions by A62.5. In effect, it provides 12 sizes in four progressive series. Yet, by carefully worked out relationships it offers hundreds of possible combinations to both the manufacturer and to the architect.

The standard A62.7 as described by Jim Parker, for vertical dimensioning, is outstanding in another utility aspect of size series. This is the concept of additivity, where some combination of preferred component dimensions will provide every possible dimension in increment of the basic unit of measure, in this case the module.

These standards build on the basic module and established graduated series of preferred sizes for dimensioning in both the horizontal and vertical plane. Together they establish the basis for the dimensional coordination of building. They are the first major breakthrough in dimensional standards for building in over three decades and will, I am sure, be viewed in later years as one of the great technical achievements in standardization.

Another basic standard shown in figure 5 establishes criteria for handling the dimensioning of joints and joining tolerance. It is given equal priority with the basis for horizontal and vertical dimensioning for it would be impossible to apply them without it.

A62 views the joint as a separate component with discrete dimensions of its own. Thus, the joint must be coordinated as a separate component and a standard written establishing a series of graduated joint dimensions and tolerances.

Following the completion of these three standards, a standard establishing rules for applying these bases

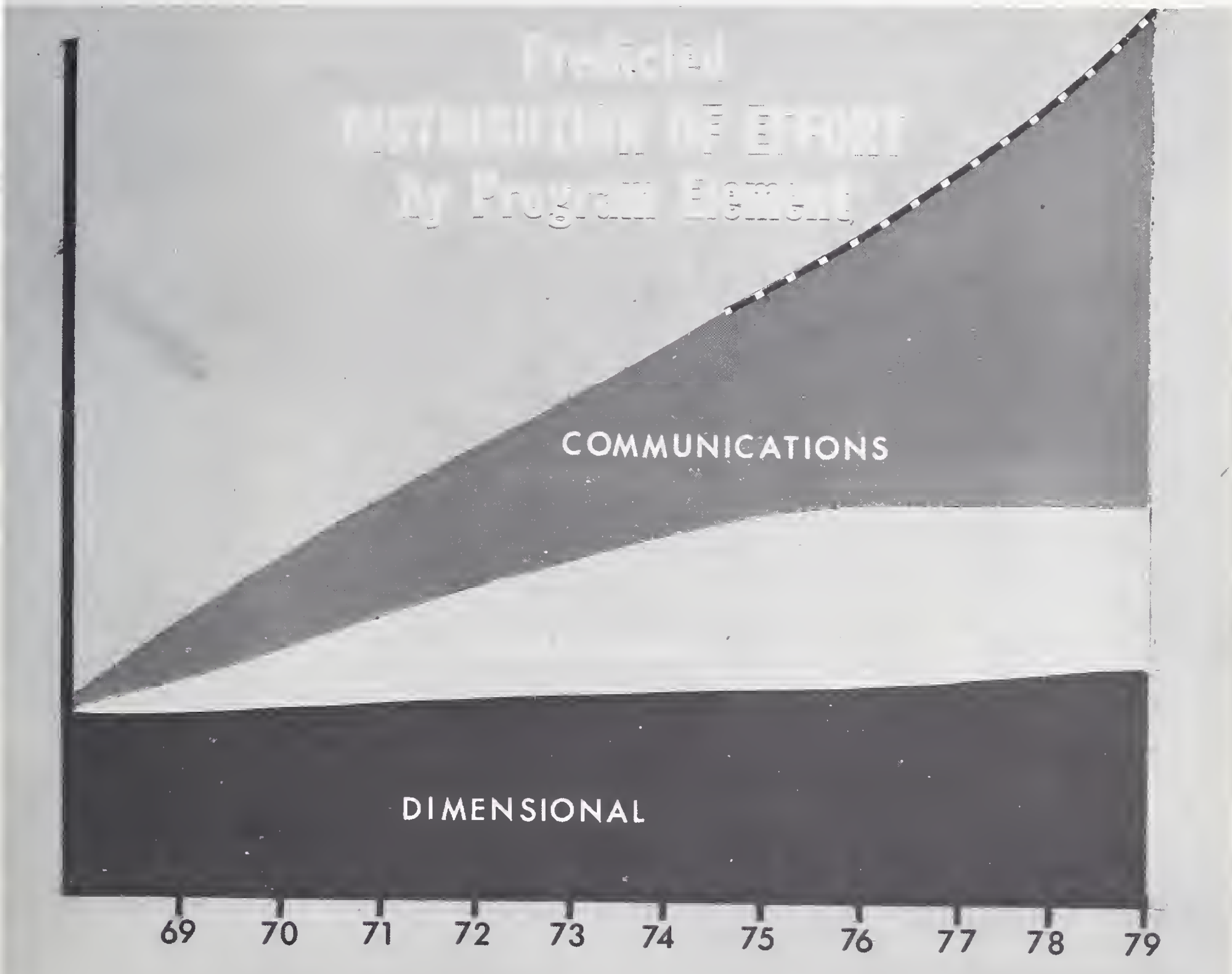


Figure 3.—*Predicted distribution of effort by program element.*

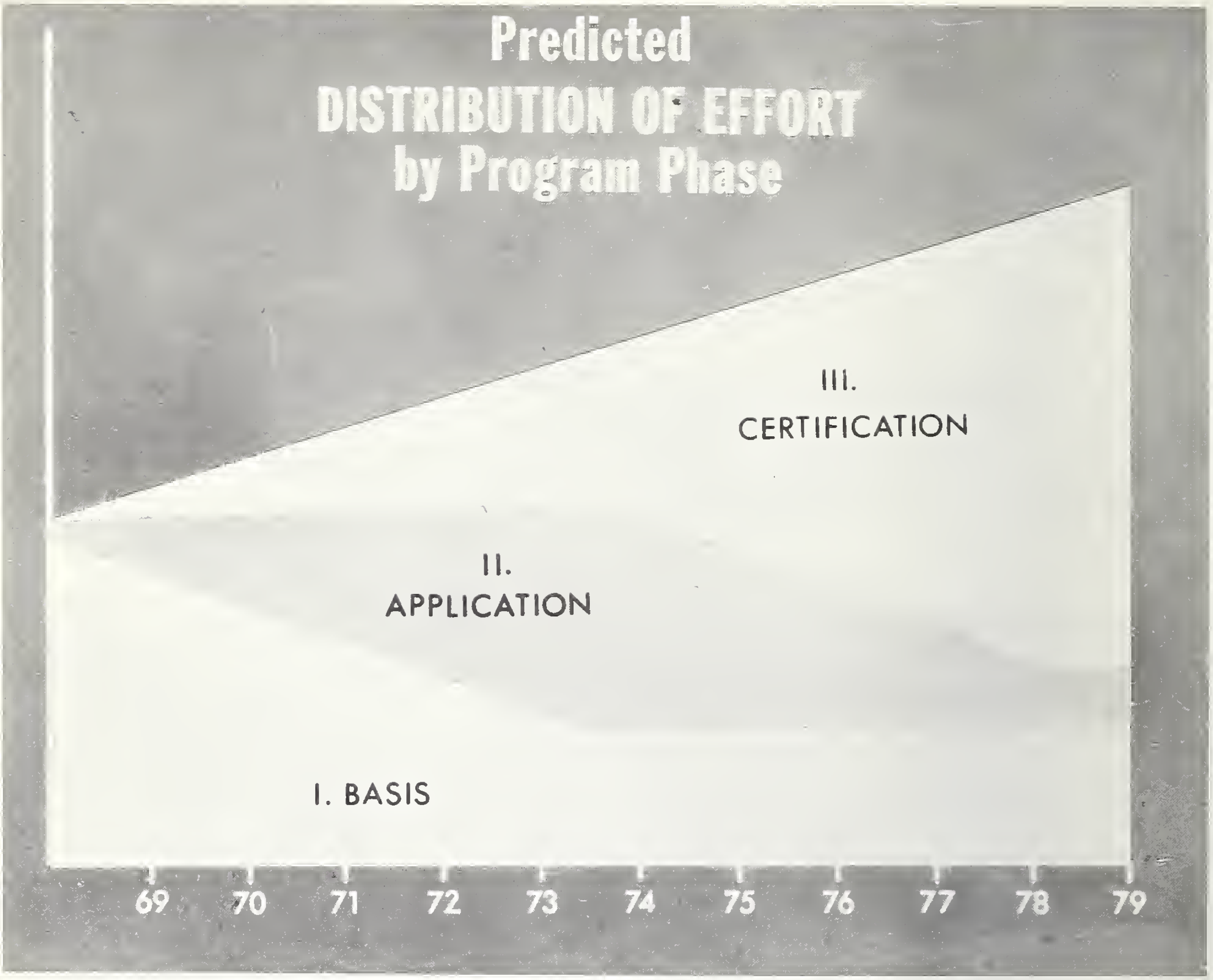


FIGURE 4.—*Predicted distribution of effort by program phase.*

of dimensioning will be developed (fig. 5). This standard will establish a system of dimensional coordination that is exclusively a development of the new A62, and may differ significantly from older systems.

Someone recently wrote to me and asked that I please send him all information on A62 Marginal Coordination. This error inadvertently describes the principle of A62 coordination better than any other term. It is truly Marginal Coordination, the interfacing of components and systems.

It will use the well-known modular grid and will provide a three-dimensional system of coordinates (or reference planes) to which the interface of components can be related.

This interface coordinate system will not be conceived as a perfect dimensional relationship but will be considered to have variations and acceptable tolerances that reflect the inaccuracies of instruments used in the field to control the layout of reference planes and/or the placing of components during construction.

It will also establish some numerical identification system for the reference planes to facilitate computer handling.

What this means is that the foundation of A62 coordination as a system of interface reference planes will determine coordinated components. The dimensioning and positioning of components, of joints, and of building design, in relation to these interface planes will be determined by other standards.

This standard, identified as A62.8 will establish a system of interface reference planes as the basis for A62 coordination. The design of components and systems, of buildings, and the assembly of buildings will then be related to this system of coordinating reference planes by subsequent standards. It will be the common denominator for coordination.

There will be several alternatives for placing components in relation to interface coordinates. These will have to be described and classified. Corner coordination will have to be effectively solved for each. The various joint dimensions will have to be provided for and tolerances established for manufacture and for fit.

It will require similar solutions to relate building design to interface coordinates, and the standard for this must cope with the tolerances and inaccuracies that must occur in assembly as well.

The erection rule standard requires establishing tolerances permissible in laying out the control grid and in placing the components in the field.

This completes the standards, now regarded as essential, for establishing a fundamental base for a coherent industrywide system of dimensional coordination in the three primary planes.

The last standard in figure 5 expands this coordination to establish preferred angles for relating components in other planes to the three primary planes; preferred radii for curved components, etc. It will complete the basis for dimensional coordination and complete Phase I activity in this program element.

Figure 8 shows the schedule for completing this activity, based on the capability of the A62 Standards Committee. By the capability of the A62 Committee, I mean the time required for making the type of thorough and meaningful analysis which will assure applicability and usefulness to the U.S. building industry. It assumes that all the necessary technical and staff assistance will be available when needed. In effect, it is the time needed to do the job, and do it right, under optimum conditions.

For over two decades, we have had standard A62.1, establishing a basic module, as a National Standard. It was the original work in the field and is the cornerstone of modular coordination throughout the world.

We also have A62.5, establishing a horizontal dimensioning discipline, now recognized as an ANSI Standard. It too is an original work in the field and will doubtless serve as a cornerstone.

The A62 Committee has completed action on A62.7, establishing a vertical dimensioning discipline, and submitted it to ANSI early this month with the recommendation it be approved as an ANSI Standard. Barring some totally unforeseen circumstances, this approval should be forthcoming in about 3 weeks.

Technical work on A62.15 is far along and a techni-

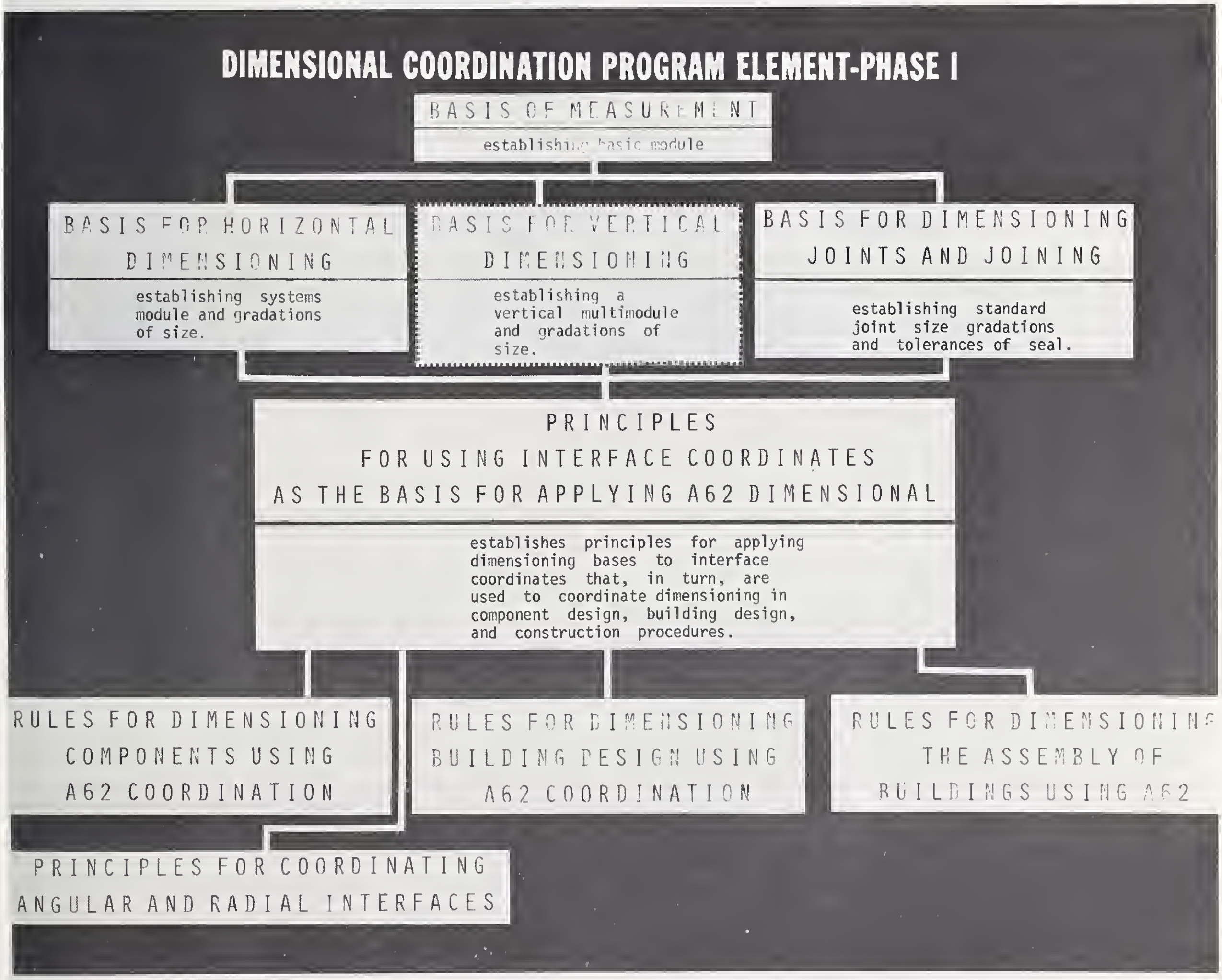


FIGURE 5.—*Dimensional coordination program element—Phase 1.*

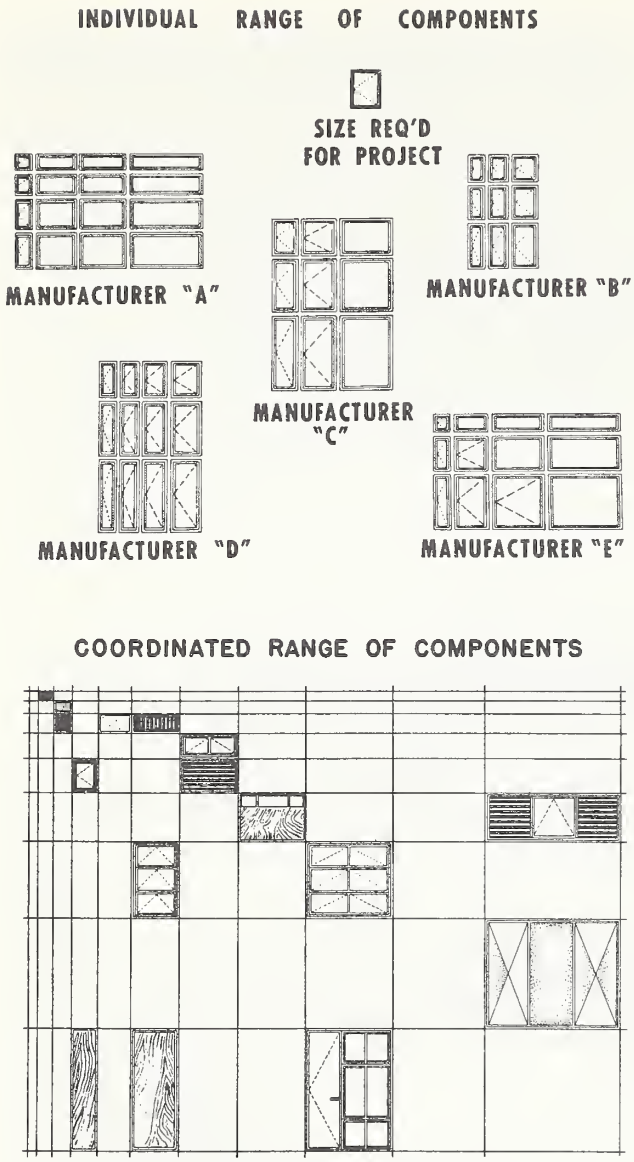


FIGURE 6.—*Individual range of components.*

cal committee to handle this standard on joints and joining is now in the process of being formed.

Preliminary technical work is only just beginning on A62.8, establishing principles of coordination. A technical committee for this standard will be formed in early 1970.

Since A62.10, application to components, and A62.11, application to building design, are based on A62.8 principles, they must await completion of this standard. It may be possible to start A62.12, assembly application, concurrently with the two preceeding standards and keep it on schedule. The schedule for A62.13, angular and radial, seems feasible.

ANSI procedure calls for the periodic reaffirmation and/or revision of existing standards. Recently, the International Standards Organization adopted 10 centimeters as the international module. In addition, there are increasing pressures on the United States to increase its use of metric measure.

It seems reasonable, therefore, that the technical committee revising A62.1 must address itself to the whole spectrum of considerations surrounding metric measure. At the center of this requirement is our opinion that any consideration of conversion of the construction industry in the United States to metric measure must involve and be built around modular coordination.

Any revision of A62.2, basis for modular masonry, will not change basic masonry coordination established in this important standard, but may be required to bring its terminology into alignment with A62.8 principles. Undoubtedly, the type of coordination now applied to masonry will be only one of several types or classes of coordination identified in A62.8.

## 6. FUNCTIONAL PROGRAM ELEMENT

Let us now look at the Phase I activity in the second program element, Functional Coordination. Rather than a sequential progression of basic standards, as in dimensional coordination, functional standardization requires an approach, best illustrated as establishing a matrix into which all other performance standardization can be plugged.

Figure 9 shows a theoretical matrix system of the type A62 plans to use as the basis of its functional coordination and the performance standardization it requires. Along one arm of the matrix is some accepted listing of the functions to be coordinated. On the other axis is some accepted listing of the components coordinated.

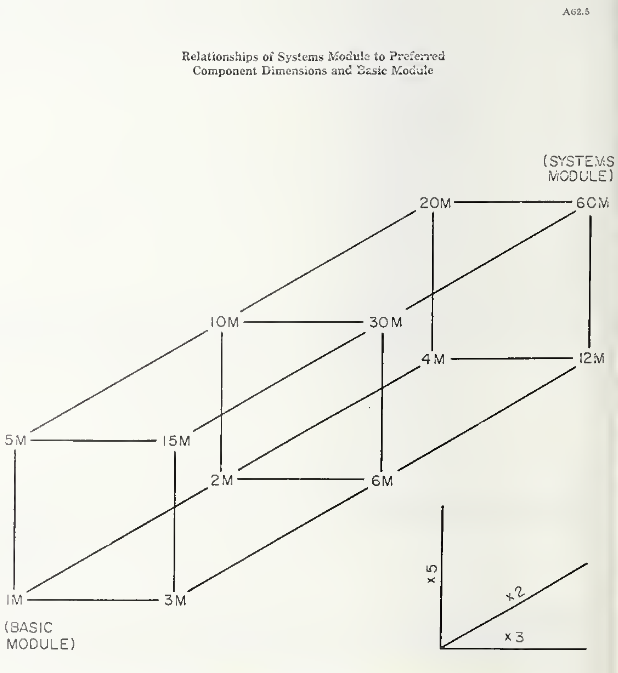


FIGURE 7.—*Relationships of systems module to preferred component dimensions and basic module.*

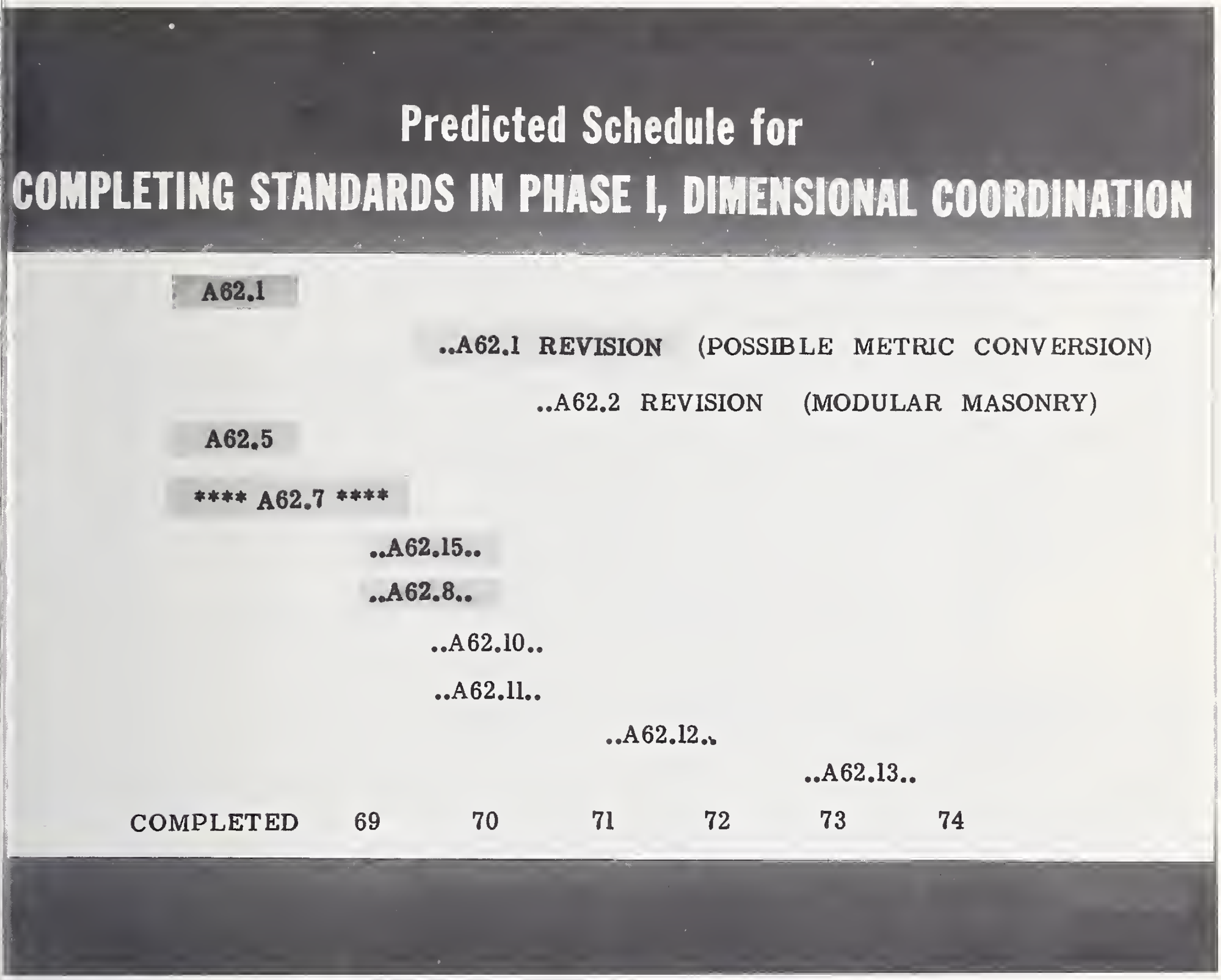


FIGURE 8.—*Predicted schedule for completing standards in Phase I, dimensional coordination.*

With this two dimensional laundry list, or matrix completed, we are able to indicate where function and component interact and, therefore, we can list those functions that require coordinating for a given component. Such an indexing is shown in figure 9a. However, at this point we cannot do much else.

But, if we assign some standard test method for measuring each function indexed, we can measure and rate the performance of this component, respective to each function. This is illustrated in figure 9b. When measurement methods are eventually assigned to all functions, we create, in effect, a three-dimensional matrix with functions on one axis, building components on another axis and a range of performance on the third axis. When the standards are completed to establish all the elements of this three-dimensional matrix, the basis for determining performance compatibility of components and systems in the U.S. building industry will be available.

Figure 10 interprets this theoretical program in terms of the actual A62 program. The first requirement is for an accepted standard listing of functions on the Y axis of the matrix by A62.6 which was approved by A62 this summer and should be published as an ANSI standard momentarily.

In developing this standard, we were fortunate to have available a "Master List of Properties of Building Materials and Products," developed by an international Working Commission of the International Council for Building Research, (CIB). This Commission had listed all the properties (for performances) of building components and materials known to be measureable.

A62 was happy to adapt this work because it answered our needs, saved several years of tedious work, and gave us a standard that was instantly in accord with the rest of the world. In addition, the CIB Working Commission is assuming responsibility for revising and keeping this list current. A62 is now requesting representation on this CIB group.

The second requirement, shown as the X axis of the matrix, is for a listing of components. Shown in figure 10 as A62.16, such a listing may have already

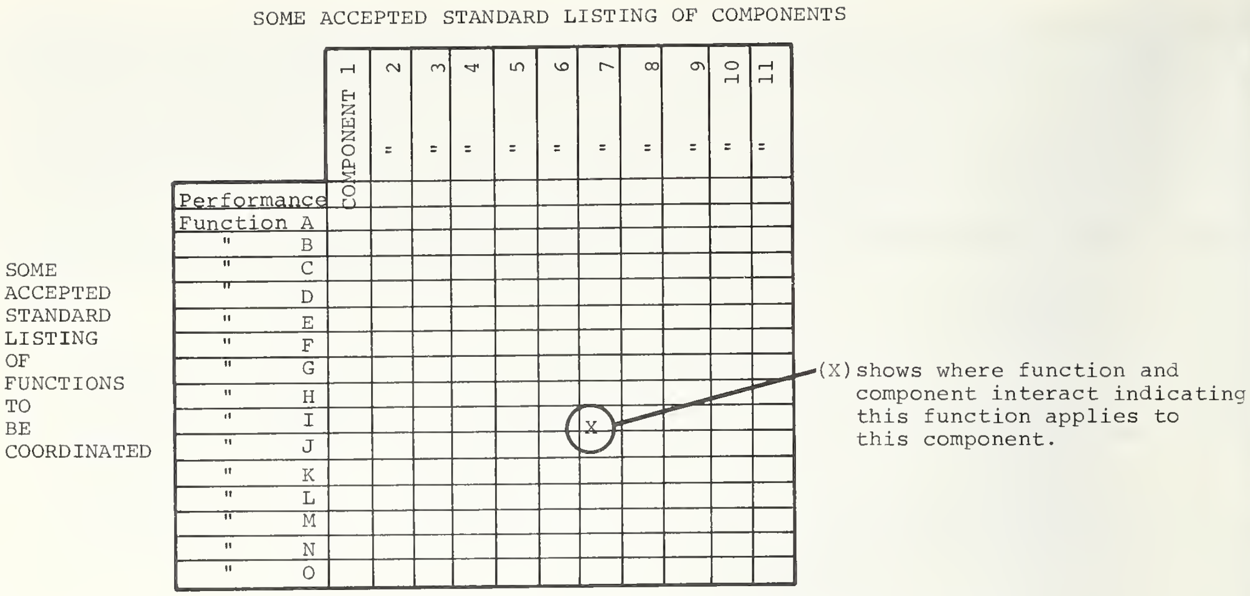


Figure 9.—*Theoretical matrix system as basis for A62 functional coordination.*

been established by industry practice. The ISO proposal referenced in this figure could also be used. If necessary, the content of the listing of components can be filled in as A62 initiates projects related to specific components.

For example, the current activity on steel doors and frames could establish these components as a category. Windows could come next, etc. Perhaps this listing of components should be kept open, and no fixed standard established.

Incidentally, A62 defines a component as any building part or components with controlled dimensions on all surfaces intended to interface with other components.

Once a project on a component category is established, a standard will be developed which indexes or lists those functions listed in A62.6 that applies to that given component. This type of standard is identified here as A62.17.

It will then be necessary for A62 to identify test methods to be used in measuring each of the functions listed for the component. In some cases there would be established standards available. In other cases methods will have to be developed. A62 will undertake

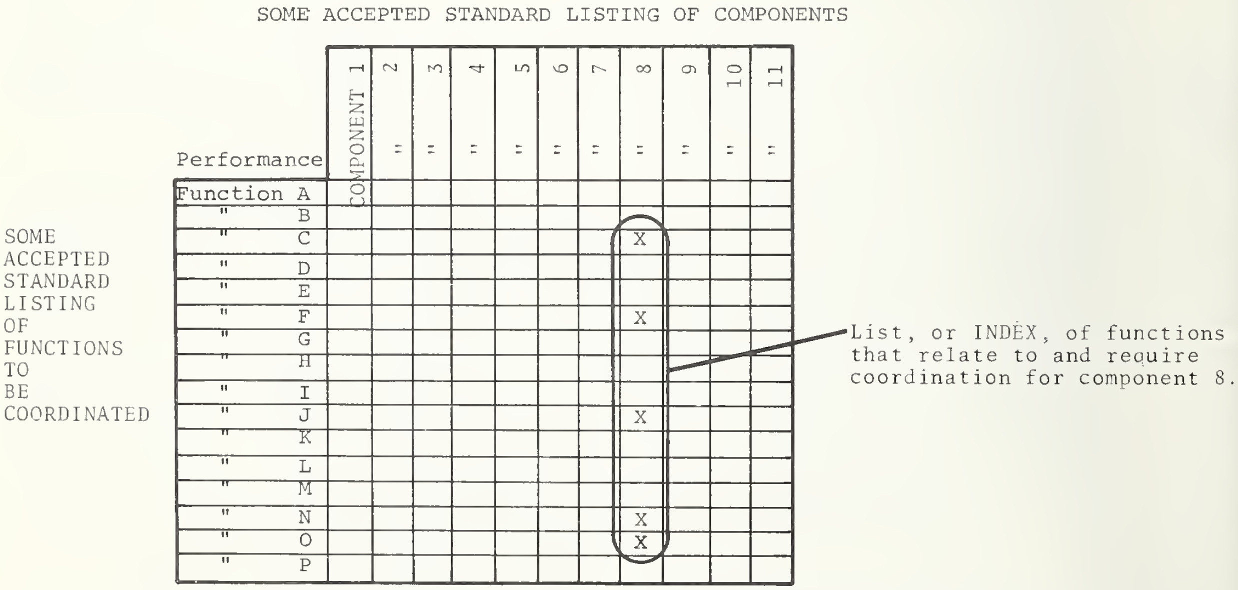


Figure 9a.—*Index of functions pertaining to a component developed by interactions on matrix.*

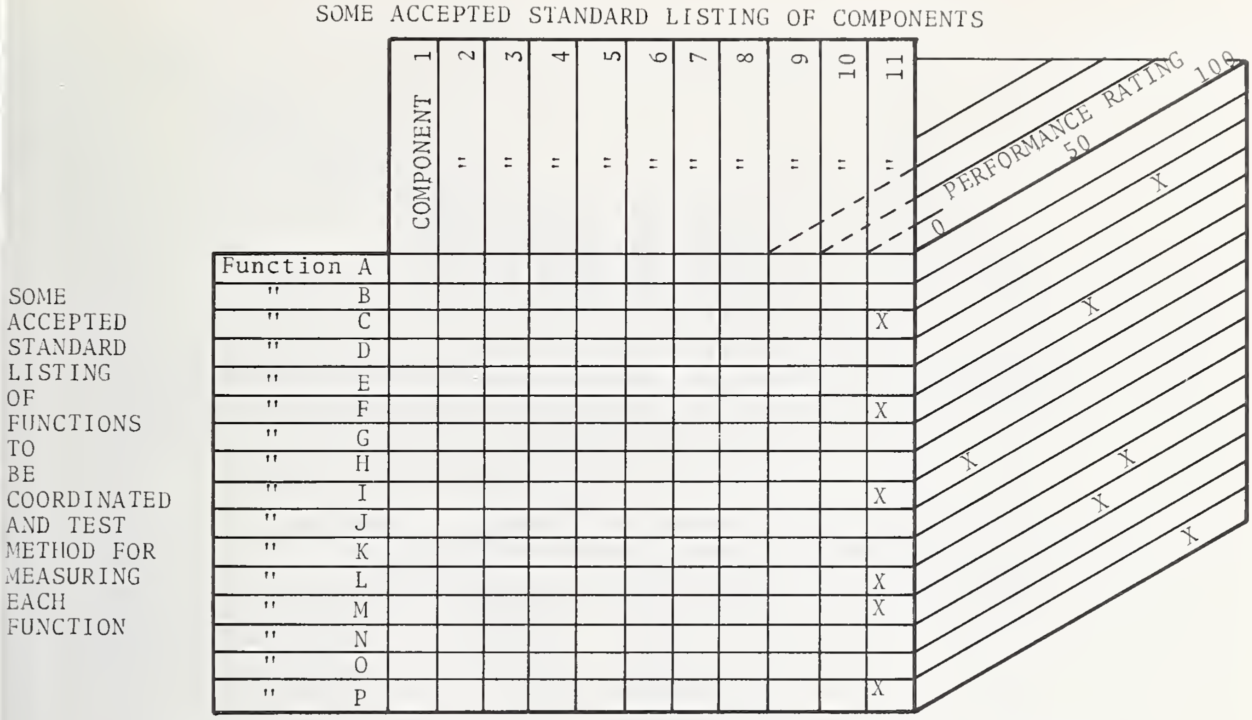


FIGURE 9b.—*Three dimensional matrix created when standard tests are designated for each function.*

measurement and test method development only under the most extreme circumstances. Normally, it will simply identify the need and refer the work to other standards bodies such as ASTM.

As components are added, tests for all functions will gradually be identified and the amount of work required for each subsequent component will be lessened. The finished matrix wil provide a standard rating system and serve as the basis for A62 functional coordination.

The ability to rate component and system performance for comparison purposes . . . to assure functional compatibility and interchangeability . . . will then have been achieved.

## 7. COMMUNICATIONS PROGRAM ELEMENT

The third A62 program element, Communications Coordination, was added to the A62 effort in late 1968 and a programing and planning subcommittee to deal with it was formed only recently. Therefore, there has been little formal planning and identification of standards that need to be developed in this area.

However, there are several distinct responsibilities assigned the communications program element which suggest certain standards and their priority.

The first of these is the requirement to develop standard drafting procedures to complement the A62 dimensional-functional coordination. This will require review, updating, and adaptation of modular drafting practices to meet current A62 requirements.

Priority will be given to meeting computer requirements. The resulting A62 system of uniform drafting practices will establish a comprehensive format for a coordinated system of computer oriented architectural drafting practices. Standards are already under development in this area.

The second area for communications coordination involves information.

Here, the requirements are for the orderly and uniform development and dissemination of information related to coordination, between A62, product manufacturers, building designers, contractors and the public. The whole concept of catalog building systems, expressed earlier in this Conference by Klaus Blach, relies on a coherent system of compatible data.

Functional coordination, particularly, is dependent on an effective information system for meaningful application. Thus, A62.6, "A Standard Listing for Functions," becomes the cornerstone of functional coordination, and for the information system required to implement it. The requirement of A62 for standards disseminating coordination information remains to be studied and identified.

This completes a hurried and very superficial summary of the A62 program.

## 8. PROGRAM POTENTIAL

It is my firm belief that completion of this program and attainment of the A62 objectives will result in the industrialization of the conventional building industry, within the existing framework of trades, suppliers, contractors, and professionals. It will maximize the efficiency and enhance the competitive position of the conventional industry. It will do this by treating the

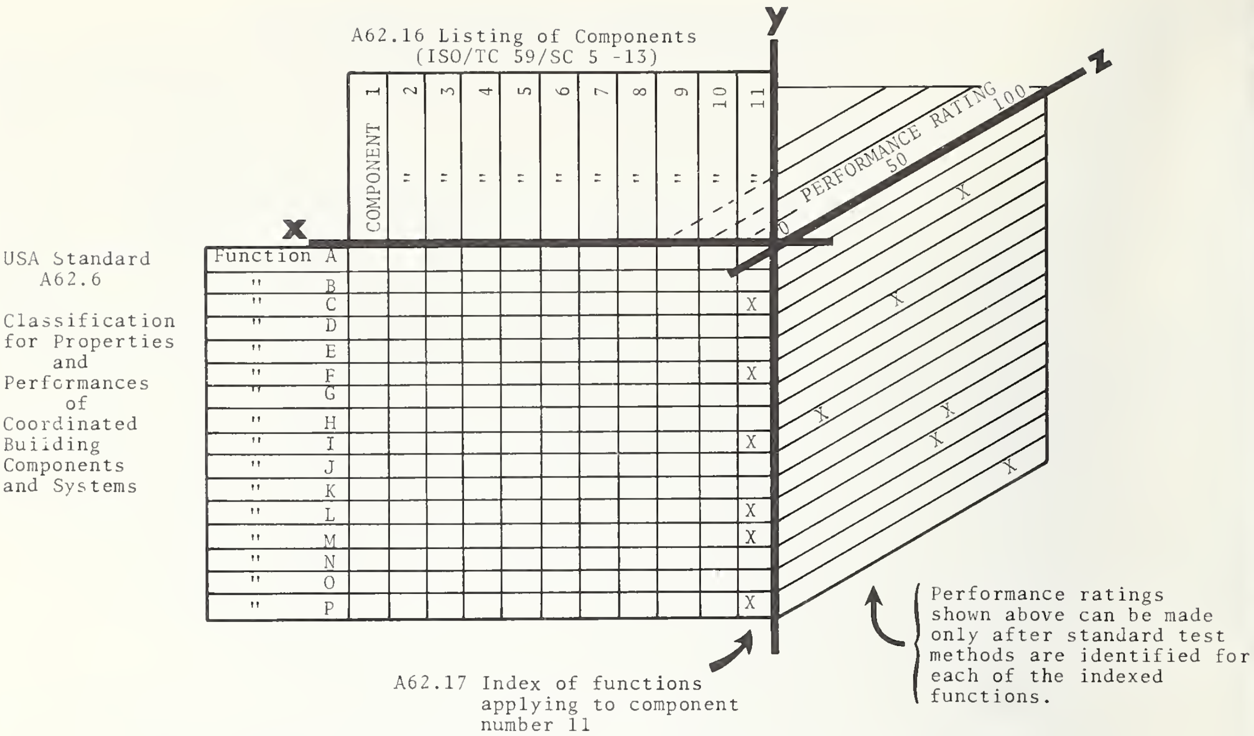


FIGURE 10.—*A62 functional coordination program related to theoretical matrix.*

existing building process as the interdependent production system it is, and develop procedures for optimizing its industrial efficiency. This can be done with only minor changes in accepted practice in most cases.

While the main thrust of the Precoordination effort must be toward applying industrial efficiency to the conventional building industry, it is recognized that so-called "industrialized building systems" will continue to emerge and grow in importance. Such systems are products of an industrial producer that mass produces them. These systems are essentialy preengineered sets of components that maximize industrial efficiency to produce a given solution. They may be sophisticated components, subsystems, or complete buildings.

In many instances, particularly where proprietary interests enter, it is possible to achieve economics in systems design by using specialized components that are not possible if the components are designed for an industrywide system as A62. It would be unfortunate if the economics inherent in systems of specialized components were restricted to single building types or to given concepts, or could be used only with specific combinations of components.

Therefore, the A62 program early recognized the need to treat these systems as they really are . . . large, complex, components . . . and provide a means for relating them to each other and to the components in the conventional, industrywide open system.

## 9. RECOMMENDATION

So much for the A62 program, I believe I am also supposed to make recommendations. There hardly seems a need for this after the speakers have so eloquently made so many, and will make others tomorrow.

These recommendations chart a course that goes far beyond the simple program of ANSI standards development I have just outlined. In effect, they place A62 at the heart of the building industry as coordinator of technological development and application.

This broader role must be assumed by some group. Why not A62? Not only can it function in this capacity . . . it already is.

As secretary of A62, and project manager of the NBS support effort, I view the A62 effort as similar to a small and poor congregation who authorized a new, expensive church. You need an awful lot of faith to start and you have to depend on God to provide the means every step of the way, and you never try to figure out how you have accomplished what you have or count up the odds against completing the job.

Since the conception of the current A62 effort over 5 years of progress has been the result of little more than the faith of a handful of dedicated men. But, somehow God has provided means and I think it appropriate, to paraphrase a cigarette commercial and say, "A62, you've come a long, long way baby!"

My only recommendation is . . . "Let's get on with the job."

# National Standards We Need In Order To Apply the Technology We Have

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This presentation explores the technology which is available to, but not yet applied to, the building industry. Specific examples of such technology, and the potential to be derived from its application to the building industry, are used. Emphasis is on the type and content of national standards needed to bring about this application.

Key words: Application of technology; available technology; required standards.

We have heard a great deal in previous presentations of work that is on-going in the development of standards for precoordination of dimensions and performance of building materials and components. Over the past 2 days the hardware utilized by the building industry has been very well reviewed from the standpoint of the precoordination required for the ordering of these materials and components into a system of building usable by the American construction industry. Speakers in the session this morning will continue this development by extending the area of consideration to include the process of communication of information necessary for the design and construction of a building, most particularly the documentation that is involved, both to support the decisions which are made and to present the results of those decisions to the men who will build the building.

What we have dwelt upon over the past 2 days are the parts that go together to make a building. They also are the parts that go together to make up a total design and construction system. What I wish to stress is that it is of paramount importance that we consider precoordination from the standpoint of the total building process. There will be more about this later, but for the moment let us merely accept for the sake of argument that all of us in the building industry will maximize our benefit and the benefit to those who use our industry if the considerations of precoordination extend forward and backward in time from the purely constructional phase in the life of a building to include all operations which take place, from the evaluation of the economic feasibility of a proposed project through the design and construction process, through the occupancy period to the eventual decision at the end of the life of a building that it must be replaced.

What I will discuss this morning, by way of introducing the material which will be treated by the speakers who follow me, is the general outline, taken from the standpoint of the architect, of the decisionmaking tool which will be available to the investor, to the designer, to the government agency, to the industrial producer, to the planner, and to the builder, if the precoordination program with which we are dealing here comes to fruition.

It is not probable that many here would argue with the need for a total system. This comprehensive approach to problem solving over time is common in many industries, though one example of which I heard recently would indicate that it is not universally followed. In that case one of our major airframe manufacturers, so I am told, currently involved in the production of an airplane of heretofore unprecedented size and passenger capacity, was considering the design of exit procedures for the aircraft. Experience with previous aircraft with no more than three or four major exits was too limited to be of much value, so an elaborate computer model was devised based on exhaustive studies of typical human beings moving from a seat to an exit under various conditions. Before very long, a very sophisticated simulation model was developed which aided the designers in locating the exits for the aircraft and deciding how many were required. The sad part of the story is that the simulation ended right there at the door of the airplane, just where the real problem in the total system begins. This points up a real problem in that industry and throws some light on the problem in the building industry. Everyone here knows the problem of the airline industry from personal experience. For a flight from New York to Chicago one must spend an hour between office and airport, perhaps another 30 minutes in the airplane waiting at the end of the runway for takeoff clearance, then the 90 minutes of flight time at 500 or 600 m.p.h., followed perhaps by another hour in a holding pattern because of heavy air traffic over Chicago, then perhaps another 30 or 45 minutes from airport to town following landing, for a total trip time of something like 4½ hours. Yet the traveling itself over the 700-mile distance at 500 m.p.h. took only some 90 minutes; the rest of the time can be considered procedural overhead and in this example it amounted to over 200 percent.

This is a little bit like the problem in the building industry. It was recently estimated that the average tenant in a public housing unit pays no more than 25 percent of his rent dollar for bricks and mortar. The other 75 cents is spent on land, insurance, interest,

equipment replacement reserve, utilities, commissions of various sorts, and maintenance.

As has been pointed out before by others, this breakdown tells us something very important about our building process. It tells us that quality buildings are a bargain. If we can, through precoordination, bring into being buildings which are of higher quality and which therefore require less expenditure for maintenance for heating, cooling, and cleaning, we are directly reducing the long-term expenses associated with occupying a building. If, furthermore, the building is more rapidly assembled or constructed, we reduce what is normally a significant item of construction expense, construction interest. This is a benefit which precoordination might achieve, totally aside from its basic intent to reduce the simple construction costs of buildings.

I do not believe it would be redundant at this point to place what we are doing in perspective. This illustration is one which I use at every opportunity and one which I suspect some in this room have seen me use before. Plotted here are the comparative price rises for two very common items in American life since the year 1900: the house and the automobile. As can be seen back around the turn of the century, one could buy a good middle-class automobile, or what passed for it then, for $2,000 or $3,000. Back then, too, a standard middle-class house was going for around the same thing, perhaps a little more. The comparative curves show very roughly what has happened to the price of each across the intervening decades. You can still buy a good middle-class automobile for $2,000 or $3,000, but the price of a house has increased manyfold. What makes all the difference here is that the automobile has been subjected to the economic rigor of industrialized production, while the individual single family middle-class house is still put together outdoors in the rain by men using hand tools to assemble many small parts on a piece-meal basis. As someone has said, the motto for the housing industry should be, "Cut to suit, beat to fit, paint to match."

Clearly, an industry so organized and so conducted will be unable to meet the requirements with which it will be faced in the years just ahead. With reference to one segment of that industry, it will be informative to look at a graph illustrating past production as compared to goals which were recently set. The solid line near the bottom of this graph indicates the approximate rate of production of low and moderate income housing units over the past two decades. The production which might normally be expected in the years ahead is indicated by the dashed extension of that line. Directly above, indicated by a sharp upward break in the curve, are the housing targets set last year by the Department of Housing and Urban Development. No one examining this graph could assume that the same old housing industry, using the same old techniques, would be capable of producing three to six times its normal gross product. And of course, last year these targets were not met, nor, it would appear, will those for present and future years be met without the sort of substantial upward revision in the capacity of the industry which the business of this conference may help to make possible. Perhaps this is the place in which to make a rather strong point. It may very reasonably be argued on the basis of experience with industrialized building here and in Europe over the year since World War II that industrialization may not, after all, substantially reduce the price of housing. However, our situation, as regards housing, is rapidly coming to be one where the most critical issue is not the cost of the housing units, but rather the ability of the housing industry to produce them at all in the numbers required. This overwhelming need, which is alarming now, but will be extraordinary over the next decade or so, emerges as a clear imperative with implications for the political stability of the Nation. When viewed in this context, and with the initial knowledge that we are gazing upon a presently untapped new market for housing and related facilities of something between $15 and $30 billion per year stretching into the misty future—a market which can only be effectively tapped by a building industry which is highly organized and very tightly integrated by the device of precoordination of materials and components as described by speakers of the last few days and utilized in a selection system such as I and the gentlemen who follow me this morning will describe. When viewed in this context, the objective of this organization appears irresistible in its appeal.

What I would like to do now is briefly describe the nature and scope of a comprehensive building design system. It goes without saying that once precoordination is an established fact with American building materials producers offering their products in a form enabling them to be used in a facile and conjunctive manner with each other, constituting in fact one large open system, it will only remain to develop an equally facile and comprehensive information system for use by those who are putting building designs together. This calls for nothing less than a complete revolution in techniques used by architects and engineers as they go about the process of building design.

The plain fact is that were precoordination to become a fact tomorrow, and were financing available, the current body of design professionals available would be completely swamped by the volume of work facing them. The only means at hand of extending their capabilities is the use of a highly automated design process equal in sophistication and flexibility to the components of the broad building system with which it deals. Architects and engineers are used to working in a drafting room with pencil and paper. The environment of the design professional in years to come will be a computer room. In this environment, he will begin consideration of a project with his client, maybe an investor, a developer, a manufacturer, a housing authority director, a school superintendent. What precoordination will do for the designer, however, is permit him to approach the design of a building with a degree of professionalism and expertise and effectiveness which he has been unable to display using the handcraft design methods which he has been using since the 18th century.

His information system will permit him to assess very quickly the economic feasibility of a project, to analyze the programs supplied him in terms of cost/benefit and to quickly make the basic design decisions which will determine the general character of his project. Then, drawing upon the combined inventory of the building-product industry, seated more than likely at a computer scope, he will be able to optimize his design for function and cost, balancing requirements and constraints. He will be able to quickly select and design the structure which will most economically and satisfactorily support the building at hand; to select the optimum heating and cooling system; to select materials and develop interior and exterior elevations with components being displayed on the computer scope before him, for his editing, if necessary, with a light pen. The site plan will be accomplished in much the same way with the computer performing tedious arithmetic required to develop the most satisfactory balancing of cut and fill, for the design of the sewer and drainage systems, together with the other utility lines, for site development and landscaping.

At each stage in this process, of course, he is relying totally upon access to a library of information established according to the standards of precoordination which have been discussed over the past 2 days. As he calls for a display of materials or components suitable for a given situation in his design, they are selected for compatibility established by the fact of their coordinations with other materials and components as indicated by the data stored for each item and displayed for the designer as he requires. When he is satisfied with his design he will not rely upon a drafting room staff to produce the necessary documents to communicate the design to bidders or to a selected builder; rather the machine will do this chore. From information which the designer has given the machine, by way of his scope and light pen, the machine produces the site plan and building plans, the building exteriors and interiors which have previously been composed by him of coordinated components and presented on scope for his editing if necessary; construction details are produced either by the computer-driven plotter or drawn from a microfilm library according to a list automatically supplied by the machine based on the detail conditions implied in the design which has been developed; mechanical drawings for the heating, cooling, plumbing, and electrical systems will also be produced by the plotter, again from information which the engineer has supplied either through scope and light pen or automatically through a program which associates such equipment with structural components selected by the designer. An important aid here will be a trouble-shooting program which can avoid the conflicts between structural and mechanical systems too often seen in today's buildings because of their forbidding complexity and the difficulty of visualizing all such situations. This is a purely mechanical function and, of course, the machine would have no such difficulty. Such programs are currently helping solve this problem in aircraft design.

Specifications, of course, will be produced by the machine as well, together with a network schedule for the erection of the building, probably with the extensions either way in time for the procedural functions that must precede and follow the construction phase. It goes without saying that a very complete cost analysis has accompanied the design of the building and it is probable that, as the building design is developed over the period of several days, tentative orders for the components involved are being entered so that by the time that the design is complete, firm prices are in hand for all components and the final price of the building can be determined immediately.

What this all means, of course, is that one or two or several men have done work over a period of several days that now takes many men many weeks to accomplish. The implications for the design professional and his productivity here are obvious. Parenthetically, two State highway departments, Pennsylvania and Florida, already accept civil engineering drawings for highway alignments with the associated grading calculated and produced by computer-driven plotters. These drawings are both more accurate than those produced by human draftsmen and more quickly produced.

This points up a very important fact. None of what I have just described is completely "blue sky." Programs for performing most of the functions mentioned are in use today in analogous situations in other industries, or in ours. The task of revolutionizing the process of communications in the building industry is largely a matter of effectively organizing presently existing capability.

It is without question true that it will be a long while before complex, one-of-a-kind buildings of a particularized nature are designed this way because of the complex problems associated with the spatial and functional relationships in such a building. But it is equally true that in a relatively simple building type, such as low-rise multifamily housing, the technical problems are of at least an approachable order, and it is here that the first innovations will be made.

It is clear from all of this that from the standpoint of precoordination, building construction must be viewed as a total process, a tightly integrated process which begins when someone decides that a building is required and ends only when that building is replaced, following the termination of its useful economic life. The cost of an item, for example, cannot be considered in the abstract, but rather must be evaluated in terms of its effectiveness in expediting the flow of the building process, and the information concerning that item which must be communicated must be complete enough so that the item's effectiveness can be readily evaluated.

Information required concerning a particular building product would of course include its dimensions and physical properties, its approximate cost, its availability, its distance from the building site to the shipping or production point, time required for delivery, and other similar information. It would also be very helpful if information suggesting its maintenance cost could be included. This is an item which looms very

large in the total cost of building and operating the American physical plant: for example, the Statistical Abstract of the United States indicates that for the typical year of 1960, the expenses of adding new space to the educational plant from kindergarten through college was approximately $3.8 billion. For the same period, the operation and maintenance of that physical plant was over half the sum, or just short of $2. This would suggest that information on life cost, or maintenance characteristics and requirements, be made available in any information system resulting from the work of this group.

With this in mind, let's go back and take a more careful look at what communications in the building industry really mean and how they work by examining the various phases in the process of getting a building designed, built, and occupied. With communications precoordination in mind, let's examine the building design process in the context of new technologies which have not yet been widely utilized in the building industries.

In the beginning someone has an idea. It may be an investor, it may be a government agency, it may be a manufacturer who needs a new plant. In any event, the questions are: What should be built? How big should it be? Where should it be? What should it be like? In this consideration we are going to exclude the exceptional building in favor of building types for which there is an overwhelming need and which will be produced in large quantities such as housing, schools, shopping facilities and the like.

Let us say, for example, that it is an apartment project that we are considering. Let us assume that the project involves several hundred units and has a budget of several million dollars, certainly a large enough project to receive sophisticated attention during its planning phase.

There are three broad conceptual areas, somewhat overlapping, of innovative work which will be of considerable importance to us. As yet, the techniques which they represent have not been productively applied in the building industry. They are the techniques of optimization, simulation, and gaming.

Let's examine the design and building process and see in each case how these and other new techniques which, as yet, have not been applied to the building industry can be used to advantage.

Now, we have gotten as far as the idea stage; someone wants a building, and it is to be an apartment project for a private owner. Obviously, the owner wants the project to be as profitable as possible, but the problem of developing a project mix, unit sizes, stages of construction, and optimum financing, is not a simple one. The techniques of such analysis have been known for some time, but the sheet mountain of arithmetic required to come anywhere near an optimum for a given set of circumstances is forbidding enough to discourage any but the more dogged analysts. Slowly coming into wider uses, however, are computer programs which drastically simplify the problem. It becomes a relatively simple matter to analyze a large number of alternative project mixes, sizes and arrangements, with the discounted cash flow being projected over the period of ownership contemplated, taking into account a number of variables such as form of ownership, varying rates of income and property taxation, estimated inflation rates and vacancy rates. It becomes then a relatively simple matter to select for further development the project that offers the most satisfactory economic return. In fact, an increasing number of professionals are forming organizations to perform just this sort of sophisticated analysis for developers of substantial projects. These professionals obviously add a great measure of assurance to a field which has traditionally been fraught with uncertainty, and information permitting this sort of analysis will certainly be a part of any future comprehensive planning and design system.

Of great promise in the area of real estate development and investment, are the techniques of urban gaming as applied to urban development. Using game theory it is possible to develop an interactive game with of number of participants assuming various roles active in the economic life of an area, and to simulate the economic deevlopment of that area over a period of many years in a space of a few hours or a day or so. It is possible thus to gain valuable insights as to the probable developments which will occur in a given locality. It is difficult to call the results predictions, but the insights gained can have very valuable implications for the developer, the school board, the city planner, or the site selection committee for the hospital.

Once the nature of the architectural program has been determined and the approximate numbers of what kinds of units to be included in the project are selected, the designers proceed with their work. They are faced immediately with a multiplicity of questions. It goes without saying that they are asked to develop a design which is pleasing to live in and which makes a positive contribution to the area in which it is located, but beyond that they are asked to locate the buildings on the site in such a way as to minimize grading and utility costs while providing satisfactory access; to select the most economical structure for the building, together with heating, cooling, plumbing, and electrical systems which provide the best performance attainable for minimum expenditure. In addition, they must coordinate dimensions and materials for maximum economy of construction.

Now, I do not believe that I will be casting aspersions on my own profession if I suggest that in the current state of affairs the architect is simply unable to do this with any real degree of success. He does not, the tools are just not there. Instead, he designs a structure which he knows from experience to be relatively satisfactory and of moderate cost; and he produces a plan which is satisfactory in terms of the materials with which it is constructed. But to suggest that he comes very close to an optimum solution, except by the sheerest and most accidental good fortune, is simply untrue. But this need not continue to be the case if precoordination becomes a fact, particularly if the development of communications in the building industry includes provision of information which will per-

nit machine analysis of the performance, cost, and dimensions of materials and components for selection by the designer.

With the design system which we are all working toward, the designer will be able to describe the requirements for the building which he is designing to the machine, in terms of its function, such items as zoning, fire code limitations and other code restrictions, budget, pertinent subsurface, and site conditions, and dimensional limitations, and cause to be presented for his consideration an array of options in geometry that are suitable for development as solutions. These options would be complete in terms of module, budget, material, structure, core design, and other prosaic considerations that normally take up an inordinate amount of time. This is not "blue sky." Neil Harper, then associate partner at Skidmore, Owings, and Merrill in Chicago, now president of the CLM Systems in Cambridge, developed a program called BOP for Building Optimization Program, which performs most of the functions I have just mentioned. It is easy to perceive what a powerful design tool such a program can be, since it makes possible a searching examination of a far wider array of design possibilities than has been economically possible for the designer before.

What is not yet possible, but is certainly attainable given the sort of information that precoordination of building communications would make available, is computer aided materials and component selection. It is not difficult to foresee a system capability which would permit the architect to interrogate a comprehensive library of materials information as to a suitable material for a given wall, for example, which must have a performance of thus and so, and certain other characteristics of this and that, and must not cost more than so much, and must be able to withstand something else. We can ask this kind of question now, but it takes an architect a day and half on the telephone to find a satisfactory answer, which is not at all to say he has found the most satisfactory answer. But it all becomes very simple, given a comprehensive communication system in the industry and a machine capable of using it, and a body of professionals proficient in its use. It is also obvious at this point that all of these capabilities can be tied together so that requirements and constraints can be balanced off to yield an optimum solution. This will make design a much more rational process and remove the arbitrariness that characterizes most of present day architectural design. A designer using this system will know exactly where the money is going in his budget and will be able to make value judgments in terms of quality, performance, and cost, with an assurance that has not been attainable in the past. The design of all of the mechanical systems in the building will be pursued in much the same way and, indeed, there are a number of good programs already in use for the calculations necessary in the design of heating and cooling systems. These programs are so good, in fact, that they tend to embarrass designers of such systems who have been proud of their performance in the past. I know of one firm whose members developed a rather sophisticated heating and cooling program and decided to use it as evidence of their expertise in soliciting further work with previous clients. They decided to take a school project which they had done some years previously and recalculate it and include it in their brochure to the school system in order to persuade the school board to give them another project. When they compared the machine analysis with the hand-done design they had performed some years before, they were so embarrassed by the inadequacies in their previous design that they decided that discretion was the better part of valor and gave up that approach to their work. To say that they are persuaded of the value of the new techniques of design is to understate the case.

The information called for by the designer in making his design decisions is presented on a scope similar to a television screen and he responds, or edits, or enters new information onto the scope in much the same way as he would draw on paper with a device called a light pen. The comprehensive design system which we are talking about will present for his consideration components to be used in developing exterior elevations, interior elevations, structure, mechanical systems, building equipment, site development: in short, everything he needs to complete his design. This is not at all to say that the machine is designing the building; rather, it is very drastically limiting the number of items he must consider by omitting automatically those solutions which do not satisfy the requirements stipulated by the architect. The important thing to remember here is that he is still designing the building, still making the same decisions he has always made, but with extraordinarily greater effectiveness.

Once these decisions are complete, moreover, the documents required to communicate them to the bidders, or the builder, will be produced not by rooms full of men drawing with pencils on paper, that is using a development of the Renaissance to draw off a product first used in ancient Egypt. Instead, these documents will be very quickly produced by computer driven plotters and other reproduction devices, thus freeing countless thousands of professional man-hours for more productive work. Professor Albright will have a good deal more to say about this I suspect. Specifications for the project will also be machine produced, at first on a language editing basis, as is current practice in many of the more sophisticated architectural and engineering firms in the country, and possibly later on a true machine generation basis, that is with specifications items automatically included through association with the information developed earlier in the design. Mr. Diehl will develop this in some detail I am certain.

Of great importance to our hypothetical apartment project owner is the cost of that project. It goes without saying that as the design has been developed there has been a running cost estimate developed at each stage so that at no point will the designer be unaware of the cost implications of the design decisions which he makes. It is possible that as time goes on, this cost estimate together with the specifications can be expanded into a link with a national materials inven-

tory, kept up to date on a real time basis, so that materials and components can be bid and ordered for a given project on a semiautomatic basis, with orders being automatically shunted to producers who are selected on the basis of cost, location, and delivery capability. This has implications that are far reaching and touch upon the structure of our industry in a way that might even interest the Justice Department. A much more exhaustive discussion of the techniques of automated cost analysis will be coming from Professor Schaffer.

Included in the documents produced for constructional building will be a complete network schedule covering every significant operation which the builder must perform, as well as ordering and delivery dates for materials and components. This schedule will be the basis for a construction management system which will monitor the progress of construction and expedite the completion of the project. This schedule would have included all of the procedural steps required during the design phase to obtain approvals and permits from local agencies and authorities having jurisdiction over the project.

All of the foregoing has sweeping implications for the future of the building industry. The truly revolutionary power of the computer as a tool of the building industry goes generally unrecognized as yet. There are architects, engineers, and sophisticated builders who use it for all it is worth at its present state of development, but they do not make a system. Only when the industry as a whole is organized to take advantage of the potential of this instrument, only then will the capacity of the building industry in America begin to expand its capability to the scale necessary to capitalize on the unprecedented market which faces it.

Many architects decry the development of this tool as one that will deprive the architect of his role, one that will dehumanize building by introducing a dulling uniformity to our buildings, one which will permit machines to make our decisions. This is "balderdash." What is happening is that the capacity of the individual to do work is being multiplied several times over. This, in fact, is an absolute necessary, for the plain fact is that there are simply not enough engineers, not enough architects, not enough builders to design and erect the construction which will be required over the next three decades, assuming today's production rates.

It is also generally unrecognized that the use of machine aides in design will increase, not decrease, building variety and the richness of the urban landscape; for as my colleague, Gary Stonebraker, pointed out, the ability of the computer to control production machinery makes infinite variety in design possible, since the computer could care less about repetitive dimensions. It is possible, even, that the use of computer aided design could mean the return of regional architectural styles. If we are to be optimizing in a given situation to achieve the most suitable architectural design for a given site, in a given locality, in a given climate, at a given time, by definition the solution arrived at will differ from a solution developed for another site, or in another locality, or in another climate, or at another time. So as the system is responsive to varying site and local conditions, it will be an influence in a direction of variety in building, rather than sameness.

So what emerges is a technical environment in which structures will be designed and built with a degree of sensitivity to a situation and a degree of sophistication that is generally unattainable today, but which will help provide us with an urban fabric of great responsiveness to specific needs. It is the role of precoordination, of communication of the building industry, to develop the information techniques which will make the system possible.

# Role of A62 Grid Coordinates in Automated Architectural Drawing

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This presentation deals with modular drafting techniques and the potential role of the three dimensional modular grid as a system of coordinates for referencing the automated storage, retrieval, and generating of achitectural drawings. In addition, the whole system of architectural drawing is examined in terms of increased automation potentials.

Key words: Automated drafting; grid coordinates; modular drafting; modular grid.

I was asked to discuss the role of grid coordinates in automated architectural drafting. I shall discuss the potential role of a three-dimensional modular grid as a system of coordinates for referencing the automated storage, retrieval, and generating of architectural graphics. The whole system of architectural drawing, which I shall refer to as graphic communication, will be examined in terms of increased automation potentials. Finally, I shall make specific recommendations relative to standards in this area. My method of presentation is from notes, with extensive use of slides, so I would like you to remember, and place into context, my comments on the basis of four very specific assumptions.

First, a large national computer network with regional operating centers connected to central data banks will emerge in the United States to serve the building industry. The time scale may be 5, 10, or 15 years.

Second, an increase in automation of graphical communications, particularly in the military areas, will greatly increase in the United States over the next 10- or 15-year period.

Third, day to day use of automated graphic systems will become economically practicable in the United States during that period.

Fourth, increased use of precoordinated industrialized building systems (open systems) will make automated communications, storage, and retrieval, not only desirable and manageable, but essential.

I always like to refer to a slide which happens to show the dining room of one of a large national chain of inns, which is using computerated drafting for production of buildings. It shows a beautiful, phony beam suspended from the ceiling, and stopping at a window without visible support. It is intriguing because it illustrates a basic concept of computerated design. This concept is the man/machine team. The man must be in there making decisions. The machine will help him, do a lot of work for him, enhance communications, but it won't necessarily avoid mistakes.

I would like to spend some time examining our entire system of architectural graphics. Zeroing in on areas for A62, I feel its work should stimulate some accelerated efforts in the interests of both the U.S. economy and our social objectives.

Let's examine the traditional way of doing things. There is program development, a preliminary sketch design, detailed work drawings, a bid award, construction, and then occupancy. Think of this in terms of the flow of graphic information drawings.

Unfortunately, this flow has evolved with not much change over the last 60 years. There is a constant translation of information from one segment to the other. I am sure you are well aware that the use of precoordinated systems will force many of the decisions, which now are made on the drawing boards by junior draftsman, back into an earlier stage.

The way that we are doing things now is really a great translation exercise. Starting with a sketch paper, a few conferences with clients, changes, handing it to the production team for working drawings, developing official documents for the bid award, or the negotiated contract, retranslating and redoing the information for assembly purposes, for the persons in the field that must assemble the buildings which work, are leak proof, and function effectively. Also, remember that the occupant needs to know where things are too, particularly in cases of a dynamic precoordinated modular system.

Well, the essence of this is that with the kinds of computer aided drawing capability which I shall describe, we really are pushing up to early design stages many of the decisions that were frequently made in later stages; up to and including change orders in the field. So, the obvious need for feedback, from the various stages of activity through a major information system, is essential. This traditionally could not be done without computers, simply because of the enormous task of correlating, identifying, indexing, and coding. When I use the word coding I am not thinking of writing a computer program, I am speaking in a general sense of communication using some specific code.

So, the real role of A62, developing standards for automated drawings for buildings, really ends up being the computer aided selection and communication standards. If we are speaking of a precoordinated open-

system of modular components, this obviously effects communications in the entire building industry.

When we speak about construction documents, thinking of the contract documents in the traditional sense of legal aspects, we are in fact, making design decisions early in the process. With precoordinated, industrialized systems, we obviously are affecting the nature of the contract and construction document situation.

Who needs to know what? Obviously, the contractor and subcontractor have to have certain graphical information. The applier, the fabricator, and the transporter as well as the financer and the approving authorities must have certain graphical information. And, quite frankly, I am always amused to enter the offices of a financial agency to see the 2-foot thick specifications, and 1-foot thick set of working drawings, which supposedly are the basis on which decisions relative to lending money are being made. Those sets of documents were not designed for that purpose. They were designed for another purpose.

Similarly, suppliers and fabricators frequently receive the kind of information that they do not need, and more seriously, they don't receive the kind of information that they do need. So, basically, a computerized graphics communication system has as one of its basic objectives the translation of one kind of drawing to another kind of sketch and then to another kind of a work order and to another kind for a delivery schedule. This is, I feel, one of the real potential advantages.

I think that it is important that we recognize, when we talk about the role of the A62 grid coordinates in automated architectural drawing, that we must think of them in terms of being compatible with our modern communications technology.

To be very specific, the publication of Modular Practice which was produced in 1962 through the Modular Standards Association, was an attempt to explain ways in which information could be communicated through drawings, taking into account the existing standards and recommendations at that time.

I am sure that we are aware that since 1962 there have been new inputs. The A62.5 horizontal standard is one, and the approved draft, as we learned yesterday, of the A62.7 vertical standard is another. Of course, what is still missing is the ability of people working in the field of automated drawings to work within a framework in line with certain recommendations.

It is important to realize that the whole field of computer drawing is a very dynamic field and I think that Russ Smith's chart yesterday, with the dotted line, shows that there is a question of the future. How extensively and how quickly will much of this kind of work play a part in the day-to-day operations of the office?

I think that there is another change that we must recognize and that is the potential to work from operating consoles. In 1963, our assessment of a direction for the planning, design, buiding, owning, operating process, was something like this: there could be something like a stockbrokers office with design professionals and operators working with video outputs. Possibly 10, 12, 14 or more video screens and other kinds of tools or scanning devices would permit observations of decisions as they were made. Coupled with hybrid computer capabilities, optimization, and trade-off benefits could be observed; not 2 or 3 weeks after the question was asked by the owner or the developer or the financier, but developed right at the time basic decisions were being made.

Finally, we see the use of what I refer to as "soft copy" drawings. Namely, the drawings on a scope or tube which can be erased until the final output in the form of the production of hard copy drawings is produced by a data plotter. We are capable of doing this in our developmental research and certain offices have some of this capability on a day-to-day basis.

In 1963, the feasibility of one of my assumptions was not as valid as it is today: the fact that the computer can be a remote operation and not right in the room. With third generation development, time sharing systems will update the console by 1975 to perhaps a major information center, replacing the traditional drawing boards, the traditional conference table, and the traditional way in which buidings are now designed in the United States.

Now there are some other factors that are important. These factors are input devices, interaction devices, and output devices. I shall quickly go through some of these. I recognize that some of you are familiar with the current state and development of computer equipment used in making drawings; however, I feel that it is important to quickly cover a spectrum of the kinds of devices which are marketed today.

Of course, we have the cathode ray tube, the tablet, or some modification of this, and the coordinate graph digitizer, and other devices. We see the cathode ray tube at work producing soft copy drawing using a light pen or other input. We see the kind of arrangement similar to a tablet, which permits both the combined use of the scope and work from preliminary sketch information. We also see the coordinate plotter which translate X, Y, and Z data into a format, through a digitizer, which automatically produces a punched card. These are not fiction, because we are using these on a day-to-day basis, not only in our research programs at Pennsylvania State University, but in our instruction programs for future professionals.

Let's look at the process in greater detail. Remember the assumption I made in my opening remarks. All this is based on there being a nationwide system of computer networks, with the regional centers and remote consoles operating at locations accessible to those concerned with producing buildings. We see input to the computer: the cards that come from the coordinate-o-graph go into the computer (which could be located 2,000 miles away). We see computation of design data which in many cases is a matter of selection of some predesigned elements. We recognized that in the graphics field, the drawing field, there will still be a lot of numerical and letter work and this is

particularly significant when we start talking about how the A62 standards will relate to the use of automated drafting or automated drawing.

Computer systems may be on-line using time sharing systems or on-line using slave computers, or batch processing (which is a traditional way that most engineering offices are doing routine preestablished design analysis). We see the output coming back in the form of data for a plotter. These kinds of devices are operating presently in many places throughout the country, including our own computerized design and construction lab at Pennsylvania State University. There are other kinds of output, in the form of hard copy, using a rotary system rather than the flat-bed system they were using earlier. In fact, elevations of a kind can be produced.

What is missing, of course, in this whole setup is the relationship to be established by the A62 grid coordination. Let's look at a typical problem and some of the graphical interaction involved. On an open-system basis, there are many walls, roofs, and mechanical systems. If one were to manually attempt to coordinate the interrelationship of these, he would have the situation as it stands today. That is conventional construction, not industrialized and not precoordinated.

So, with the tremendous power of the computer, backed by a man who is making intelligent decisions and telling the computer what to do, we really are making optimum selections—selections of the materials, subassemblies and assemblies or more specifically, components or systems, or even total building systems. More importantly, we are concerned with ways of interfacing these various kinds of components and systems when we work in the graphical automated mode.

Tied in with this is the fact that without an information and storage retrieval system, it would be very difficult to extract and transfer essential information from the memory of the computer to the operator-designer, who in turn could make certain decisions.

Let's look at graphic communications. There is nothing today to prevent a person from taking the cathode ray tube and using it for a lot of graphical operations. What is missing, however, is the link between the programs that are written, and the requirements to establish relationship through the A62 activities. This, I assume, is why I have been asked to speak.

For instance, if one is working with the cathode ray tube, using light pen selection of materials, he must have some way of referencing his work with a system. We now have ability on the horizon for material selection and graphical interaction as total systems, and this is really amplifying many of the comments Mr. Cogswell made preceeding me this morning.

The real question, I would ask you, is where do I point the light pen if I really want to work with that kind of a system. True, any individual organization can develop its own standard for referencing points, when using visual communications of this kind. However, I think that it is a mistake and a waste of national resources, millions of dollars, for many people to be writing different computer programs if some very basic standards could be established at an early date. Such standards could put the input procedures in a commonly identified and understood format.

This is a very important point for those of us working in the field of computer drawings when we are speaking of working with open systems and the total building process. Similarly, even if we are working with a furniture arrangement or in a landscaping office, we need reference points which are geared to work with the capability of the computer and its memory system.

The current A62 standards (and there is nothing which I object to in the current standards) do not address themselves to this problem. As Russell Smith pointed out yesterday, these are next in line. The plea here is that those persons working in this area, who have had experience in the problems, get in at the early stages and establish standards for referencing positions.

We are living in a different age of communication, but, if we do not look ahead we will end up by solving the wrong problem brilliantly. Consider the matter of partition components. Isn't there obviously a need to be able to identify their position by referencing one location that means something not only to the computer, but to the designer, the fabricator and the person concerned with the entire standards picture. An A62 grid system will do this.

I think that you recognized from what I have said, that this will facilitate a component data bank, a data bank with the right information for retrieval in a way that will work with graphical systems. A lot of U.S. dollars will go down the drain if we don't coordinate our efforts.

Let's develop standards in this field so that we can proceed with work in the right direction and not redo a lot of work that has previously been done. I might cite our own experiences. From 1963 to now, in work for the National Science Foundation and other agencies, we have had to design fictitious referencing systems because we did not have national standards to which we could refer. Now, it may be all right for one or two groups to do this to learn what the needs are; but, if every office in the country establishes its own referencing systems, incompatible with others and with standards promulgated in the future, we certainly would be taking a step 20 years backwards rather than 20 years forward.

What is very important is that we build a data base which establishes facts concerning components, their properties, and their characteristics. Similarly, in automated graphic systems it is essential to work with a commonality of reference coordinates to position a component or system.

Briefly, a marketable system relates the problems of tolerances, joints, and coded information. Some questions that must be answered are: How do we reference its position in a geometrical sense? Do you reference the lower left hand corner, the upper right hand corner, or its center? These are the kinds of things that should be established by A62 standards so that the many

groups working on computer program development and software will not be working in vain or needlessly reinventing the wheel.

It is essential that the geometry of building, as a computer input, be top priority on any list for standardization. I am not saying that the components program that uses this input has to be standardized, but it is essential that the geometrical characteristics of relationship to some system of three dimensional coordinates be standardized.

Even if one is working with soft copy with a cathode ray tube that goes into the memory of the system and ultimately comes out as hard copy on a plotter, it is essential that certain standards be established in this direction.

Also, if one is to retrieve information concerning various components and systems, it must be presented in a way that (regardless of the kind of program, or area, or office using it) is meaningful without a lot of translations.

Computer programs are one area where standardization should not occur. We have a great variety of computers and of languages in the United States. People are writing programs of great variety. But, if the input and the output in final form are standardized, we can proceed with bigger jobs. We want to be able to use many kinds of programs. Traditionally these are the kinds of programs that many architect-engineer offices have been using on a batch processing basis. These need to be linked together to interrelate in the entire building design problem. Importantly, we want a commonality for referencing positions.

Any standard which is developed should very clearly spell out requirements. Any three-dimensional grid system certainly should not conflict with the present two A62 standards for horizontal and vertical sizes. But, what is needed now is pulling them togeher in a way that is meaningful to the persons involved with computer drawings. More important, I feel it must be compatible with the present systems which are used in most offices working with the grid system. Although many of us feel that we must move ahead, particularly those of us educating the future professionals for the building industry, I consider it essential that some decisions be made first, in order to help clarify the direction in which we are going.

If basic standards are established, I can see no reason why American industry cannot come forth with a truly identifiable system of dimensional coordination. I think one of the bonuses we will achieve, with the development of A62 type systems of standards is that (Mr. Cogswell really hit this one) onsite expense for change orders and interferences will be reduced quite vividly. With a "3–D" numerical referencing system, interface mistakes could be detected in a way which you probably could never achieve today unless you built a model. I recognize that many chemical industries do build models to verify in three dimensions, clearance and interference problems. The coordinates of an A62 standard will do the same for buildings on a general basis.

It is traditional, I think, that in the working stages of conventional production of construction documents, we tend to work on flat surfaces. We work with planes, horizontally, and we work with planes, vertically. It requires a tremendous amount of ability, time, and dollars in man power in order to double check where interferences occur. So now, obviously, the interferences do not get caught until on the jobsite and added costs for changes are necessary.

In 1969, when we can achieve great space marvels, we certainly should be able to do better in the aspect of precoordination. Certain decisions must be made to avoid excessive costs in computer program writing, in computer program running time, and for program development, if researchers and design groups are to move ahead. A Standard 3–D reference grid must have meaning at many kinds of decision levels, whether it is in basic block diagrams, architectural studies, details, or assembly diagrams for erection of components. All require some reference coding of 3–D.

Relative to automated equipment, I am not saying that the digitizer is the answer to graphical input. I am not saying that cathode ray tubes, with light pens, and all their other driving capabilities are the answer. I am not saying that tablets are the answer. But, I am saying that the developers of, and the persons working with, automated procedures, must have some basic standards for input and output.

I would hate to see hundreds of firms and millions of dollars in investment being expended on perpetuating, or simply converting some noncomputerized approach. The real potentials of the computer are in the 3–D drafting situations. If we all develop nonstandard coding systems, we are very unrealistic and when it comes time to produce buidings at that rate, and in the time frame that we are all concerned with, we will fail.

I have six recommendations which I shall read.

First, A62 should establish a numerical, or an alpha numerical, 3–D refeernce system standard for X, Y, and Z coordinates. Such standards should coexist and not conflict with existing regular drawing procedures. It is obvious to those of us working with example work that modular drafting publications should be updated very quickly, particularly in light of the last two A62 horizontal and vertical standards established.

My second recommendation is this. A62 should establish standards for a common reference point on individual component products. I realize that there is a lot of ground work to be done before this can be accomplished, but for those of us who are working with automated drawings and looking at it as a national problem, it is essential that there be a common reference which means something to all of us. At the moment, I am thinking of a geometrical reference but property characteristics should not be ignored.

Three, A62 should establish recommended procedures for automated graphic output. The kind of thing which occurs as the result of a computerized process, such as from a flat-bed plotter. I would encourage that this be done in such a way that the output can ultimately be integrated with noncomputerized information in one document.

Recommendation four, A62 should not attempt to establish standards for the manner in which computer programs for computerized drawings are written. We must have many machines, many languages, and many programers used for many different purposes.

Five, A62 should encourage establishment and maintenance of a computerized national data bank. When I say national, I do not mean Federal, I mean national, for data on evaluated open-system components now in production. And, I would encourage that this be started with the larger systems first; the room-size modules; the environmental systems; and then moving down the ladder to the smaller elements. This may be quite contrary to approaches which many persons think should be taken. That is to start small and go big, but if we look at the need for data bank information and the need for precoordinated industrialized construction, I feel the larger module should be established first in a data bank.

There will be interfacing problems in establishing the data bank. Certain regional computer centers will perhaps need translaters to get information in and out, but this is not a major problem once the ground rules are established.

And, finally, the last recommendation was described yesterday in connection with the rate of effort. I urge that the communication aspects, which I have discussed, and which others today are concerned with, be moved into some earlier stages of A62 standards development activity. I think until this is done, we, as a Nation, are wasting valuable manpower, valuable time, and not solving the building needs. I did not say housing. Housing is obviously important. But, I feel that we have got to look at the entire building situation.

This concludes my formal comments. I do have one final plea. I feel that it is essential that a body of competent professionals must be educated and reeducated to serve the needs of the Nation. What we as a group, as an industry, as citizens, as professionals are doing to stimulate outstanding young men in high school to come into the building industry is embarrassing. I think we must recognize that in our society today, significant decisions are made by men from what they hear on the radio and see on television.

If we are going to move in the direction which I described, it is essential that all of us find ways to communicate with junior high school and high school students, and with the younger men in our offices who would be willing to train or to continue their educations in order to bring to construction the advanced techniques.

# Precoordination for Automated Cost Estimating

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Fundamental to the success of implementing an unrestrictive open system of precoordinated building that can include any component or any building system is the capability of being able to estimate the value of each particular product of this system in its onsite environment over its life-cycle of existence. This capability requires a precoordinated cost estimation process which is as unrestrictive an open system as is the precoordinated building one itself. An example of the development of an open-ended implementation for cost estimation is presented in this paper. The implementation is COBESTCO—COmputer Based EStimating Techniques for COnstruction.

Key words: Building process; COBESTCO; cost estimation.

## 1. INTRODUCTION

It is well known that in precoordinated building each facet of the process must be assessed in terms of the value in the facet's contribution when examined with regard to the precoordinated building process considered as a whole. It is well known, for example, that if a specific concept, procedure, material, specification, construction mode or any other facet associated with precoordinated building results in a high (or higher) cost/benefit ratio for the product to which a specific concept, procedure, etc., is applied, the specific concept, etc., cannot be acepted as a serious professional contribution to precoordinated building. It may be that the specific concept is considered to be outstanding when compared to alternate concepts; however, it is in the result of the entire process—the product—wherein the contribution of the specific concept, etc., must be evaluated for assessing its real value. Hence, a value judgement limited to only a facet is illusionary at best.

It is also well-known, of course, that fundamental in assessing value is the measure of cost. In precoordinated building, however, this cost must reflect the life-cycle of the product in-place for it is truely this level of consideration to which the whole of the process of precoordination is directed. Thus, although there exists a tendency to assess the value of an effort in precoordination in terms of a particular phase of the product's life-cycle—design, construction, operation, maintenance, repair or replacement—the effort must be evaluated in terms of its total utility over its lifespan; that is, over all of its phases of its lifespan. It is recognized that in certain lengths of life-cycles on specific products, particular types of costs have controlling influence in ascertaining the total utility of the product; however, this fact in no way diminishes the basic import of the use of costs which reflect the entire life-cycle of the product.

This argument provides one performance standard in precoordination for automated cost estimating as required in an unrestrictive open system of precoordinated building:

1. Costs must allow for calculation of value of product over its life-cycle as well as within each of its phases.

Other performance standards are developed in the next section. In the third section an automated cost estimating procedure is described which exemplifies an implementation of standards such as these to an open system of estimating construction costs. The last section contains conclusions and recommendations for future work.

## 2. PERFORMANCE STANDARDS

An unrestrictive open system of precoordination that can include any type of component or building design —the advertised focus of this conference—exposes a complexity in combinatorial accounting which defies quantification.

With such complexity it is neither feasible nor possible to develop a list of operating standards which can account for every possible combination. Accordingly, only a performance type of standard can be advanced.

The performance standards advocated for precoordination for cost estimating are given in table 1. It is believed that these standards will allow for a cost estimating process that can accommodate the open system of precoordination in building being discussed in this conference. This is not to claim that the list given is necessarily the best or complete; the reader may well be able to include additional standards. However, it is thought to be a responsible first start.

It is thought that these standards are essentially self-explanatory; hence, only selected comments seem necessary. One is on standard No. 6, viz, costs being available on a timely basis. For costs to be so available it is necessary that they be on an automated basis. The numerous combinations of components and systems possible for each product and with each combina-

**Table 1.—Performance standards for precoordinated building**

1. Costs must allow for calculation of value of product over its life cycle as well as within each of its facets.
2. Costs must allow for calculation on any combination of entities that result in any product to be erected in any environment.
3. Costs must allow for use in any mathematical model for purposes of calculating any measure of value.
4. Costs must admit effective consideration of new entities as discovered and new mathematical models as developed.
5. Costs must be in the form required to allow their uses by the professionals in all aspects of the product life-cycle.
6. Costs must be in the form required to be easily accessible to all professionals on a timely basis.
7. Costs must be of the form required to allow for their correlation and correspondence among the functions within any organization and between any organizations that could be associated with a product.

tion having to be valued over the product's life-cycle precludes the feasibility of manual calculations. Hence, it can be seen that the reference to automation in the title of this presentation is in direct response to Standard No. 6.

A comment is also appropriate on Standard No. 3. This standard reveals that new measures of costs are required. The existing techniques are not sufficient to cope with the complexity presented with precoordination. Hence, attempts to merely extrapolate existing procedures to provide cost estimating for precoordinated building would be futile; the new complexity demands new measures. No discussion on possible new cost measures is given in this work.

No other comments are thought to be necessary.

## 3. COBESTCO

An examination of the performance standards reveals that the development of a cost estimating procedure which satisfies these performance standards is a difficult chore at best. Clearly, such a development requires complete, coordinated and comprehensive planning in order to make the cost estimating procedure as open a system as is the system of precoordination to which it is being applied. To increase the chances of success in achieving such flexibility it behooves one to examine other attempts at complete, coordinated and comprehensive planning for developing procedures which are specified only by performance standards. One such attempt with which your speaker is acquainted is COBESTCO; i.e., COmputer Based EStimating Technique for COntractors.[1] This attempt is discussed in this section.

The discussion begins with a listing of the performance standards for the estimating process which resulted in COBESTCO. The process developed to implement these standards is then described. Brief descriptions on the steps in the process are then given in terms of an example application. A discussion of experience on its use concludes this aspect of this paper.

### 3.1 Performance Standards

The performance standards for an estimating process which would meet the needs of the constructor in today's environment are given in table 2. It is seen from Standard No. 1 that the estimator's personal judgement based on experience is to be maintained. Standard No. 5 requires a computer-based procedure in that no manual procedure can be used to meet such a requirement in the short time span available to the contractor for preparing an estimate. Standard No. 2 can be met with the use of numerous planning/scheduling procedures; all must be accommodated. However, COBESTCO emphasizes use of CPM. With this emphasis on CPM it follows from Standard No. 3 that the operations must be defined to be able to meet CPM needs and those of cost accounting simultaneously.

### 3.2 Process

The process developed in COBESTCO to allow for the implementation of these performance standards is given in figure 1. However, before proceeding with an explanation of the steps in this process, a discussion on some of the salient features of COBESTCO which reflect it's open-endedness is in order.

Consider first the numerous points-of-view; i.e., judgements, held by contractors on how production rates of crews or equipment fleets should be measured. Some contractors believe that production rates of crews and equipment fleets should be measured only in terms such as cubic yards per day, square feet per hour., etc., with no identification of the crew or equipment fleet composition. Others take the opposite

**Table 2.—Performance standards for constructor estimating**

1. Process of estimating must be sufficiently broad so that it can service any construction firm irrespective of the firm's size and location, type of work, existing concepts of estimating and existing concepts of control systems.
2. Process of estimating must allow for formal planning/scheduling procedures to be associated directly with estimate and such that the depth of detail desired in either the estimating or the planning/scheduling procedures can be satisfied.
3. Process of estimating must allow for representation of operations as defined for purposes of planning/scheduling to be in 1 : 1 correspondence with types of entries used for cost correspondence with types of entries used for cost control.
4. Process of estimating must result in output that can serve the constructor's informational needs in estimating, control and planning/scheduling simultaneously.
5. Process of estimating must allow estimator sufficient opportunity for his reviewing alternates of his choosing in construction methods, without jeopardizing his ability to submit bid on-time.
6. Process of estimating must admit the use of historical records whenever desired but must also allow for their neglect when desired.

[1] COBESTCO, CRS No. 7, Department of Civil Engineering, University of Illinois.

position that the crew composition is the primary measure but that only durations of field operations are to be measured. Still others maintain that only unit costs of work-in-progress are important for production rate measures. And some contractors will use some combination of these and other types of entries. As a general principle it can be stated that all contractors use all of these types of entries in their measuring of onsite phenomena but most probably no two will necessarily use the same type of entry for the same operation. COBESTCO allows for any type of entry desired by any contractor on any operation.

Not only is the judgment of the contractor necessary in measuring onsite phenomena, it is also paramount in the design of his control devices; that is, cost accounting, progress reporting, material purchasing, etc. In these areas it is also doubtful that any two contractors would agree completely on such procedures in all their details. However, again COBESTCO accommodates such flexibility; it allows each contractor to impose the controls he desires in the form he prefers.

Of course, the contractor's judgment relative to the estimating process itself must be considered also. There are numerous approaches to the estimating process. Some claim that there are as many approaches as there are estimators. Others claim that there is no unique approach but rather it will vary according to the project. Be that as it may, COBESTCO is designed to accommodate any approach desired by any estimator on any project.

Thus, it is seen that COBESTCO is a general, rather flexible procedure which could be used in its present form in numerous construction companies. COBESTCO allows complete freedom in defining operations for a project; thus, it is "project-type free." COBESTCO can accommodate all mature cost accounting procedures in virtually their existing forms; thus, it is "company free." COBESTCO provides essentially unlimited freedom to estimators in selecting where and in what forms to enter information leading to the evaluation of costs for labor, equipment, material, and subcontracted work; thus, it is "estimator free." Finally, COBESTCO requires and allows contractor personnel to include judgment and experience factors wherever necessary; thus, it is "not man free."

Clarification of these capabilities of COBESTCO will become apparent with the discussion of its process. This process will be discussed assuming a single project and that a Critical Path (CPM) network of the project will have been prepared by the estimator for his purpose. Although preparing such a network is not essential in applying COBESTCO, it does allow for such a procedure. Such a procedure has the definite advantage of interrelating estimating and the construction planning in definitive terms. It is agreed that the estimator must visualize a feasible construction process in order to arrive at an appropriate cost estimate. It is also agreed that immediately preceeding construction the construction process should be developed in detail. It is a matter of record that in many cases when the construction process is developed in detail it evolves in a plan that differs fundamentally from that proposed by the estimator. Because the detailed plan is in general generated after the award of the work, the company may have unwittingly become involved with a sour job. The use of a CPM network in estimating doesn't eliminate this possibility completely, but it does provide a mechanism which, if properly applied, can greatly reduce its chance of occurrence.

COBESTCO can accommodate as detailed a CPM network as desired; in fact, it can accommodate the complete detailed plan of the construction process. Morever, because COBESTCO automates the Quantity Take-Off process, extensions of labor, material, equipment, material and subcontract costs, it also provides for the time required for generating the CPM network in the estimating process. Accordingly, it has the internal capability as well as the management characteristics required to allow for an estimating procedure which can include a detailed consideration of the construction process itself.

It is also to be noted that COBESTCO is concerned only with costing a job and not pricing a job; it neglects the profit strategy.

The process of COBESTCO is given in figure 1. The major steps as identified in the figure are:

1. Basic Decisions.
2. Define Operations.
3. Define Estimating Units.
4. Collect Numerical Information.
5. Process Data—Intermediate.
6. Develop Project Schedule.
7. Develop Costs Dependent Upon Project Schedule.
8. Process Data—Final.
9. Select Estimate Form.

1. Basic Decisions; prior to any estimating effort, the responsible contractor personnel must make basic decisions on such items as probable construction methods, major equipment items, expected productivity on the site, work to be sublet, etc.

2. Define Operations; after finalizing the Basic Decisions, the project is described in terms of operations which can be used to plan and schedule the construction process via the Critical Path Method. Examples of typical acceptable operation definitions are given in figure 2. It is to be emphasized that the operations are described on the level of detail as required only for the estimate.

3. Define Estimating Units; once the CPM operations are defined the next objective is to subdivide these operations further in such a way that the resulting parts are: (1) small enough so that their costs can be estimated directly, and are (2) compatible with the company's cost accounting system. Both of these objectives are achieved simultaneously by using the definitions of the firm's cost accounts as criteria for subdividing the content of the CPM-operations. This is accomplished by listing with each operation those cost accounts which are associated with the particular types of work which each defined CPM-operation

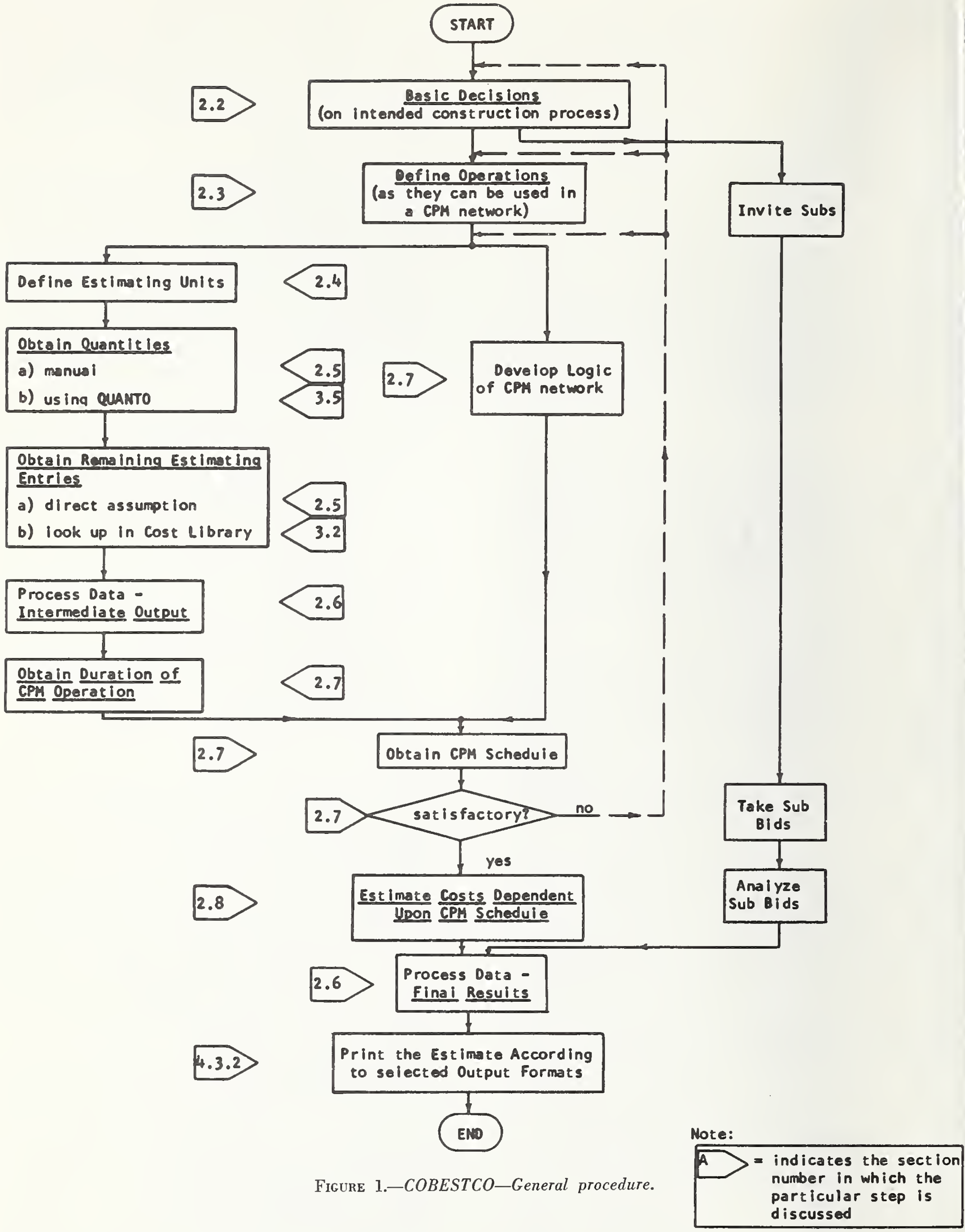


FIGURE 1.—*COBESTCO—General procedure.*

| Integer No. | (No more than 30 characters and spaces) |
|---|---|
| 40 | EXCAVATE BLDG. INCLUDING TANKS |
| 42 | INSTALL TANK SLAB |
| 48 | EXCAVATE DRAIN DITCH |
| 50 | ALL CONCR. WORK EXCEPT SLABS |
| 52 | UNDERFLOOR ELECTRICAL WORK |

FIGURE 2.—*Examples of acceptable operation definitions.*

requires; it is important that each of these cost accounts refers to a well defined basic construction activity.

These well defined basic construction activities are called Estimating Units. Each of these Estimating Unit records has as its first entry a decimal extension of the CPM-operation number to which it is assigned and, as a second entry, the corresponding cost account number. Thus, it is seen that the content of an Estimating Unit is defined by its simultaneous association with an operation as well as a cost account.

Figure 3 illustrates the assigning of Estimating Units to an operation using the example operation: 50–ALL CONCR, WORK EXCEPT SLABS. It seems clear that the number of Estimating Units into which a CPM-operation must be structured is a function of the comprehensiveness of the operation definition relative to those of the selected cost accounts.

4. Collecting Numerical Information; the Estimating Unit furnishes the necessary form wherein to include the information required to perform the estimating process. The next step is to evaluate and properly record, step-by-step, for each Estimating Unit, all of the entries which are are to be processed to generate the respective costs and the duration of the Estimating Unit.

Such information can be generated in three ways: (1) By assumption; (2) from the plans and specifications; or (3) by retrieval from the Cost Library included in a company's version of COBESTCO. The Cost Library consists of historical production and cost information stored in files which are identified by cost account numbers. The cost account number associated with the Estimating Unit serves as the reference for selecting the appropriate file from the Cost Library.

COBESTCO can accept a wide variety of numerical entries in many units of dimension, chosen and dimensioned as desired by contractor personnel in any firm; the computer is programmed to accept all standard dimensional forms and to convert them as required. The wide variety of numerical entries which are permissible can be classified into the following types:

1. Quantity entries.
2. Time entries.
3. Crew production entries.

| Operation No. + decimal extension | Cost Account | Verbal Description |
|---|---|---|
| 50.05 | 1150.02 | FOUND |
| 50.10 | 1150.05 | |
| 50.15 | 1151.85 | COLUMN FIBER TUBE FORMS |
| 50.20 | 1150.07 | |
| 50.25 | 1220.10 | |
| 50.30 | 1260.05 | WALL |
| 50.35 | 1021.26 | |
| 50.40 | 1021.20 | |
| 50.45 | 1021.17 | |
| 50.50 | 1160.15 | |
| 50.55 | 1160.05 | CURE WITH WET BURLAP |
| 50.60 | 1150.95 | ADD FOR CARP. FOREMAN |
| 50.65 | 9010.05 | |

FIGURE 3.—*Estimating units for operation: 50-ALL CONCR. WORK EXCEPT SLABS*

4. Labor cost entries.
5. Equipment cost entries.
6. Material cost entries.
7. Cost entries for Subcontracted Work.
8. Total cost entries.
9. Certain additional entries for variables which are common to all Estimating Units.

Examination of figure 4 can reveal the character of each of these types of entries. It is merely to be empasized that all of these units can be entered as desired in any combination in any Estimating Unit.

Typical complete records of several Estimating Units employing these numerical entries are given in figure 5.

5. and 8. Process Data—Intermediate; Process Data—Final; these two major steps can be discussed simultaneously. Each data processing step operates on the information stored in the record of the Estimating Unit. Data processing consists of two stages: in the first stage, arithmetic operations for various extensions are performed on the numerical data in each Estimating Unit and in the second stage, the results of the first stage are subjected to various summations.

The arithmetic operations involved in the extensions lead to the following measures per Estimating Unit: Quantity, duration, and the applicable entries of the five cost values; labor, equipment, material, subcontracted items, and total. Data processing is fully automated; the computer is programmed to select the proper formulation from among the computational possibilities listed in figure 6.

After all the various extensions are completed, various summations operations are performed to obtain the values for more comprehensive project subdivisions which sets of Estimating Units constitute. As stated previously, the Estimating Unit is the most detailed breakdown of a project which is made.

No essential differences exist between the major steps Processing Data—Intermediate and Processing Data—Final. In each of these, the same arithmetic and summation operations are performed. They differ only in the spectrum of input available at the time of their performances. Only Estimating Units regarding operations considered individually are available when the Process Data—Intermediate step is performed. These plus Estimating Units reflecting costs based upon the project schedule; i.e., the collection of operations, are available for Process Data—Final.

7. Develop Costs Dependent Upon Project Completion Time; in this step the costs are developed which cannot be generated until the project schedule is known. Such costs include such items as rental of equipment, supervision, etc. These costs are entered in COBESTCO via appropriate Estimating Units.

9. Output Form Selection; the last major step in COBESTCO is the selection of the forms in which to display the estimate. There are seven such forms; the titles are given in figure 7. The exact contents of these forms will be clarified with the example problem.

### 3.3 The Cost Library

As stated in the discussion of step 4, Collect Numerical Information, numerical information is transmitted into the Estimating Units via three sources: (1) A Cost Library; (2) assumption; and (3) plans and specifications. It is instructive to examine the implementation involved with the Cost Library.

The use of this source involves the information retrieval feature in COBESTCO. The initiation of this information retrieval is controlled by the Cost Account number of the Estimating Unit. For example, in figure 5 the Cost Account 450.05 initiates information retrieval whereas 1151.85 does not. If the decimal portion of the account number is less than or equal to 79—like 05 in 450.05—the information retrieval feature in COBESTCO is initiated automatically; if the decimal portion is greater than 79, it is not. Thus, accounts 1151.85, 1150.95, 4410.85, 2510.90, and 3103.85 in figure 5 do not initiate information retrieval.

Now, the Cost Library itself is structured in terms of a hierarchical structure assumed in COBESTCO. COBESTCO requires that accounts be standardized; i.e., definitions of cost accounts remain unchanged from project to project. Although this requirement may require a rather extensive system of accounts, these accounts can be generated over time as required and COBESTCO is programmed to handle essentially an unlimited number of accounts.

The hierarchy of cost accounts is described explicitly in the example Cost Library given in figure 8. Consider the entry on the first line; i.e.,

P 400 EXCAVATION, BACKFILL, HAULING

This is called a Principal Work Classification account and refers to major, general classifications of work. In this example the "400" series refers to the classifications Excavation, Backfill, Hauling Costs that cannot be charged directly to Principal Work Classification accounts; rather their verbal descriptions are used as headings in the estimate reports.

Consider now the entry on the second line:

*450 BLDG. EXCAVATION

This is called a Main Cost Account. Ninety-nine Main Cost Accounts can be associated with each Principal Work Account where each Main Cost Account is associated with a specific type of work included in a general classification. It is seen that in figure 8 a total of five Main Cost Accounts are associated with the 400 Principal Work Classification Accounts. These are:

*450 BLDG. EXCAVATION
*451 DRAINAGE EXCAVATION
*460 BLDG. EXCAVATION BACKFILL
*470 HAULING EXCAV MATERIAL
*480 SITE EXCAVATION & GRADING

Acceptable Entries for Estimating Unit Records

| Type | Label | Magnitude | Dimension Symbol | Explanation of Dimension |
|---|---|---|---|---|
| **Quantity** | | | | |
| | | | FT | foot (feet) |
| | | | SF | square foot (feet) |
| | | Any | CF | cubic foot (feet) |
| | | Integer | YD | yard(s) |
| | (none) | or | SY | square yard(s) |
| | | Decimal | CY | cubic yard(s) |
| | | Number | EA | unit(s) or piece(s) |
| | | | LB | pound(s) |
| | | | TN | ton(s) |
| | | | GL | gallon(s) |
| **Time** | | Any | | |
| Actual | | Integer | HR | hour(s) |
| time | (none) | or | DAY or DAYS | day, days |
| Value | | Decimal | WK | week(s) |
| | | Number | MO | month(s) |
| Overtime ratio | OVERT | Integer | none | - - |
| **Cost** | | | | |
| lump sum | | | $ | dollar |
| cost per | LAB | Any | $/FT | dollar per foot |
| unit of | | | $/SF | dollar per square foot |
| quantity | EQU | Integer | $/CY | dollar per cubic foot |
| | | | $/EA | dollar each |
| | MAT | or | $/LB | dollar per pound |
| | SUB | Decimal | $/GL | dollar per gallon |
| | TOTAL | Number | $/HR | dollar per hour |
| cost per | | | $/DAY | dollar per day |
| unit of | | | $/WK | dollar per week |
| time | | | $/MO | dollar per month |
| **Crew-Production** | | | | |
| | | | FT/HR | feet per hour |
| | | Any | SF/HR | square feet per hour |
| | | | CY/HR | cubic yards per hour |
| proper | | Integer | EA/HR | units or pieces per hour |
| production | none | or | LB/HR | pounds per hour |
| value | | | GL/HR | gallons per hour |
| | | Decimal | FT/DAY | feet per day |
| | | Number | SF/DAY | square feet per day |
| | | | CY/DAY | cubic feet per day |
| | | | TN/DAY | tons per day |
| Crew efficiency | EFF* | Integer or | none | - - |
| crew level | LEV* | Decimal No. | none | - - |

* in case this variable is omitted from input, it is automatically set equal to 1.0.

FIGURE 4.—*Acceptable entries for estimating unit records.*

Typical Complete Records of Estimating Units

| Op. No. & Decimal Extension | Cost Account | Numerical Entries |
|---|---|---|
| 40.1 | 450.05 | 400 CY/DAY ** |
| 40.2 | 450.10 | 60 CY, EFF .9, LEV 3, OVERT 20 ** |
| 50.3 | 1151.85 | FORM ROUND COLS. 28 FT, LAB 4.00 $/HR ** |
| 50.96 | 1150.95 | CARP. FORM, 4 DAYS, LAB 4.00 $/HR ** |
| 85.1 | 4410.85 | SUB 2000.00 $, 10 DAYS ** |
| 130.5 | 2510.90 | LIGHT STEEL FRAME 49 TN, 15TN/DAY, LAB 164.00$/DAY * EQU 132.00 $/DAY, MAT 210.00 $/TN ** |
| 100.1 | 3103.85 | 5250 SF, MAT .30 $/SF, LAB $/SF, 1.5 DAYS ** |

FIGURE 5.—*Typical complete records of estimating units.*

Again, only the verbal descriptions of these accounts have utility.

The cost accounts to which charges can be made are the accounts with decimal portions; that is, like 450.05. These account numbers are the ones which appear in the records of the Estimating Units and are used to distinguish among the various ways in which specific types of work are accomplished in terms of the site conditions which can influence their measurements. For example, the account 450.05 refers to BLDG. EXCAVATION PERFORMED BY A ½ CY BACKHOE. A total of 79 of these accounts can be associated with each Main Cost Account; that is, 79 various ways can be considered for each type of work and would be indicated in the 450 series as 450.01 through 450.79. The 79-limit results because of the automatic information retrieval feature associated with the decimal portion value of less than 80.

Each of these cost accounts contain 5 entries in the Cost Library and are numbered in sets of five in figure 8. Each entry can contain only specified information where each entry is represented by one IBM card. These are shown in figure 9. For example, Card No. 1 contains ID information as well as explanatory information on the cost account which is non-retrievable. Card No. 2 contains the ID information, the date of the establishment of the record, title information for the estimate, and the production rate measure of the method considered in the cost account. Card No. 3 is the Unit Price Card and Cards No. 4 and No. 5 are the crew composition cards. It is not necessary that every entry on every card be filled; any choice can be made as long as entries which would lead to contradictory information are avoided. COBESTCO is programed to indicate errors resulting from conflicting information and will prohibit such processing.

Examples of typical Cost Account records are given in figure 8. It is noted that the No. 4 and No. 5 cards; i.e., the crew composition card, define crews in the numerical mode. In 450.05 the crew consists of two 100's, one 161, one 162, and one 695. Information which is common to all Estimating Units is entered in the numerical mode; these include wage rates of crafts, equipment rental rates, and the ratios of overtime to regular-time rate for both men and equipment. Crafts are referred to with a number in the range on through 499 and equipment with one from 500 to 999. This information is given in figure 10. Thus, the crew composition of two 100's refers to two laborers; one 161-a crane operator; one 162—an oiler; and one 695—a one half yard backhoe. Although the numbering scheme is arbitrary, when once defined in a company it must be maintained. It is to be noted that craft rates are entered as dollars per hour and equipment rates as dollars per day.

### 3.4 Automated Quantity Take-Off

In the example of Estimating Units presented to date, the quantity entries were always included by definition. These quantities can also be obtained automatically for a limited number of quantities; for example, those which are represented by quantities associated with poured-in-place concrete items. This feature requires a separate input package.

An example of this input package is given in figure 11. Consider the building segment 4 BURIED COLUMNS. The first card in this set is a Dimension card. This card states that there are four columns, each of which have a diameter of 1.0 feet and a height of 9.8 feet. The descriptor, COLUMN, is an entry in a Program Oriented Language mode. This descriptor itself is defined as follows:

> COLUMN: Any column that is rectangular or circular in cross-section. The volume and form area are calculated.

This descriptor signals these calculations. All of the other descriptors have the same type of characteristics.

It is to be noted that certain labels to add volume, subtract volume, etc. are also possible. These are indi-

1. <u>Time</u>

$$T = \frac{Q}{PR \times LEV \times EFF}$$

2. <u>Quantity or Fuel Consumption</u>

$$Q = n \cdot f\ (\text{plan dimensions})$$

$$C = T \times CT$$

3. <u>Labor Cost</u>

$$LC = \frac{Q \times LCQ}{EFF}\left(1 + \frac{OVERT \times (RATIO1 - 1)}{100}\right)$$

$$LC = T \times LCT \times LEV\left(1 + \frac{OVERT \times (RATIO1 - 1)}{100}\right)$$

4. <u>Equipment Cost</u>

$$EC = \frac{Q \times ECQ}{EFF}\left(1 + \frac{OVERT \times (RATIO2 - 1)}{100}\right)$$

$$EC = T \times ECT \times LEV\left(1 + \frac{OVERT \times (RATIO2 - 1)}{100}\right)$$

5. <u>Material Cost</u>

$$MC = Q \times MCQ$$
$$= C \times MCQ$$
$$MC = T \times MCT \times LEV$$

6. <u>Cost of Subcontracted Work</u>

$$SC = Q \times SCQ$$

7. <u>Total Cost</u>

$$TC = Q \times TCQ$$
$$= T \times TCT$$
$$= LC + EL + MC + SC$$

Notation

T = time (may be direct working time as well as time say a certain piece of equipment is at the site).

Q = quantity (may be an extension of plan dimensions or only a value indicating the number of pieces like doors, joists etc.).

C = consumption (fuel, oil, water, etc.).

PR = crew production rate of a specified men or man-machine combination, i.e., the "crew").

LEV = ratio of size of the intended crew to that stored in cost library.

EFF = crew efficiency, EFF = 1.0 means average condition.

n = number of identical structure members.

f() = computation rules which must be applied to arrive at quantity starting but from the respective plan dimension (compare Section 3.5.3).

CT = consumption per unit of time

LC = labor cost in $

LCT = labor cost per unit of time

LCQ = labor cost per unit of quantity

EC = equipment cost in $

ECT = equipment cost per unit of time

ECQ = equipment cost per unit of quantity

MC = material cost in $

MCT = material cost per unit of time

MCQ = material cost per unit of quantity

SC = cost of subcontracted work in $

SCQ = cost of subcontracted work per unit of quantity

TC = total cost

TCT = total cost per unit of time

TCQ = total cost per unit of quantity

FIGURE 6.—*Formulations in COBESTCO.*

OUTPUT FORMS OF COBESTCO

```
No. 2   Detailed Estimate in Terms of Project Operations

No. 3   Summary of Estimate in Terms of Project Operations

No. 6   Detailed Estimate in Terms of Cost Accounts

No. 7   Recap of Principal Work Classification Accounts

No. 8   Recap of Estimate

No. 9   Echo Print of Input
```

FIGURE 7.—*Forms of COBESTCO.*

cated in the building segment SPREAD FOOTINGS FOR COLUMNS.

*Example Output*

The various features of COBESTCO have been discussed as separate entries. The application of COBESTCO is actually merely a collection of these features (fig. 12). The results of an application are shown in figure 13. (Detailed estimate—ordered by operations), figure 14. (Summary of estimate—ordered by operations), figure 15. (Detailed estimate—ordered by costs accounts); and figure 16. (Estimate recap).

### 3.5 Conclusions

A considerable amount of detail has been presented in this paper. Although such an amount of detail cannot in general be recommended in a paper, an exception is necessary when the discussion is directed to a subject like estimating. Estimating construction costs in its present stage of development is a process burdened with detail and any discussion of it must emphasize rather than ignore the minute series of steps involved in obtaining and integrating bits of information in the process. Further, it is just the existence of this detail that makes computer-based estimating attractive.

The output for example problem just presented was obtained in 70 seconds utilizing the IBM 1401–7094 computing system of the Department of Computer Science of the University of Illinois, Urbana, Ill.—less time than that required for merely the column takeoff done manually. Assuming a commercial rate of $550 per hour for a '94" system, this would represent a cost of $11. The cost to make estimate extensions, then, would be 0.03 percent of project cost. The total cost of estimate preparation was not checked carefully, but because of the dictaphone approach to data preparation, it is thought that $100 would be a conservative figure—0.25 percent of project cost. Cost figures like these make computer-based estimating, and COBESTCO in particular, quite attractive.

However, it is not intended to imply that COBESTCO in its present form is the ultimate answer to computer based estimating. COBESTCO was a research effort to examine the feasibility of a general purpose computer program which any estimator working in any firm could use to estimate the construction costs of any type of project wherein the latest technology as well as contractor experience could be accommodated as desired. COBESTCO proves one thing—it's feasible.

## 4. CONCLUSIONS—RECOMMENDATIONS

The conclusion on COBESTCO per se is that it is at least a feasible implementation of an automated estimating process for use by any contractor in any firm for use on any project such that the information required for the estimating, accounting, planning, and scheduling functions separately in his firm can be coordinated completely. This can be taken as evidence of the viability of an approach based upon performance standards applied to the development of a computer-based system which encompasses great complexity because of a requirement of open-endedness. This realization leads to the first conclusion: Namely, that the approach which led to COBESTCO can be recommended for use in developing an automated estimating procedure for precoordinated building.

Of course, only the approach of COBESTCO can be recommended. The detail of COBESTCO may or may not be useful; hence it can only be treated as suggestive. However, the detail of COBESTCO can be used to indicate limitations contained therein that must be overcome in an acceptable automated estimating process in precoordinated building. These include:

1. COBESTCO is programed for only one configuration of computer hardware of only one manufacturer.
2. COBESTCO is programed for only one type of cost accounting procedure.
3. COBESTCO is programed for only one mode of planning and scheduling a project.

```
COST LIBRARY

P     400             EXCAVATION. BACKFILL. HAULING
*     450             BLDG. EXCAVATION
1     450.05
2     450.05 NOV.64  1/2 CY - BACKHOE
3     450.05
4     450.05   2-101   1-161   1-162   1-695
5     450.05
1     450.10
2     450.10 DEC.64  ADD. HANDEXCAVAT.                    10 CY/DAY
3     450.10
4     450.10   1-100
5     450.10
*     451             DRAINAGE EXCAVATION
1     451.15
2     451.15 SEP.64  DITCH TILL D=5 FT                   400 CY/DAY
3     451.15
4     451.15   1-101   1-161   1-162   1-695
5     451.15
*     460             BLDG. EXCAVATION  BACKFILL
1     460.10
2     460.10 OCT.64  BACKF.W/FRONTENDL.
3     460.10
4     460.10   1-100   1-163   1-560
5     460.10
1     460.50
2     460.50 DEC.64  COMPACT W/AIRTRAMP
3     460.50
4     460.50   2-163   2-770   2-771
5     460.50
1     460.60
2     460.60 DEC.64  GRAVEL LAY.IN BLDG                   80 CY/DAY
3     460.60
4     460.60   3-100   2-163   1-560   1-916
5     460.60
1     460.70
2     460.70 MAY 64  BACKFILL W/GRADER
3     460.70
4     460.70   1-100   2-163   1-556   1-770   1-771
5     460.70
*     470             HAULING OF EXCAV.MATERIAL
1     470.15
2     470.15 SEP.64  6-CY  TRUCK
3     470.15
4     470.15   1-400   1-505
5     470.15
*     480             SITE EXCAVATION AND GRADING
P    1000             CONCRETE WORK
*    1021             POUR CONCR. W/CRANE AND BUCKET
1    1021.14           (NO MAJOR HOIST OR TRAVEL INCL.)
2    1021.14 DEC.64  GRADE SLABS                          80 CY/DAY
3    1021.14                        18.00 $/CY
4    1021.14   3-102   1-163   1-916   1-930
5    1021.14
```

FIGURE 8.—*Cost library.*

Formats of Cost Account Record in Cost Library

Card 1:

| Column Nos. | Entry |
|---|---|
| * 1 | The number 1 |
| * 4-11 | Account No. (dec. point in Col. 9) |
| 12-72 | any explanatory comment, (cannot be extracted) |

Card 2:

| Column Nos. | Entry |
|---|---|
| * 1 | The number 2 |
| * 4-11 | Account No. (dec. point in Col. 9) |
| 13-18 | Date record was established or updated |
| 21-38 | Explanatory text to be transmitted to estimate each time record is called |
| 51-58 | Production of crew |
| 59-64 | Dimension of production (See Table 3.5) |

Card 3:

| Column Nos. | Entry |
|---|---|
| * 1 | The number 3 |
| * 4-11 | Account No. (dec. point in Col. 9) |
| 17-22 | LAB cost |
| 28-33 | EQU cost $/unit of quantity |
| 39-44 | MAT cost (Integer or decimal |
| 50-55 | SUB cost number somewhere in |
| 61-66 | TOTAL cost allotted field) |

Card 4:

| Column Nos. | Entry |
|---|---|
| * 1 | The number 4 |
| * 4-11 | Account No. (dec. point in Col. 9) |
| (a) 14-15 | No. of following resource |
| (b) 17-19 | Identification No. of resources |
| 22-23 | Same as a |
| 25-27 | " b |
| 30-31 | " a |
| 33-35 | " b |
| 38-39 | " a |
| 41-43 | " b |
| 46-47 | " a |
| 49-51 | " b |
| 54-55 | " a |
| 57-59 | " b |
| 62-63 | " a |
| 65-67 | " b |

Card 5:

| Column Nos. | Entry |
|---|---|
| * 1 | The number 5 |
| * 4-11 | Account No. (dec. point in Col. 9) |

Remainder identical to Card No. 4

* These entries must always be punched even if remaining part of the card is blank.

FIGURE 9.—*Formats of cost accounts record in cost library.*

WAGE RATES AND EQUIPMENT RENTS

| 2.0 | 1.5 | |
|---|---|---|
| 100 | LABORER | 3.25 |
| 101 | LABOR FOREM. | 3.60 |
| 102 | CONCR. LABOR | 3.35 |
| 120 | CARPENTER | 4.45 |
| 121 | CARP. FOREMAN | 4.80 |
| 122 | CARP. HELPER | 3.50 |
| 130 | CEMENT FIN. | 4.45 |
| 140 | BRICKLAYER | 4.85 |
| 141 | BR. L. FOREMAN | 5.20 |
| 150 | IRON WORKER | 4.85 |
| 151 | STR. ST. FORM. | 5.25 |
| 152 | STR. ST. HELP. | 3.30 |
| 161 | CRANE OPERATOR | 4.65 |
| 162 | OILER | 3.80 |
| 163 | SMALL EQUIP. OP. | 3.80 |
| 164 | LARGE EQUIP. OP. | 4.65 |
| 300 | ELECTRICIAN | 4.95 |
| 310 | PLUMBER | 4.95 |
| 400 | TRUCK DRIVER | 3.40 |
| 505 | 6CY-REAR DUMP | 80.00 |
| 556 | LIGHT GRADER | 60.00 |
| 560 | FR. END LOADER | 70.00 |
| 602 | CRANE 1 CY | 100.00 |
| 695 | BACKHOE 1/2Y | 60.00 |
| 770 | AIR TRAMP | 5.00 |
| 771 | AIR HOSE | 1.50 |
| 781 | AIR COMPR. | 25.00 |
| 916 | VIBRATOR | 5.00 |
| 930 | CONCR. BUCKET | 3.00 |
| | END | |

FIGURE 10.—*Wage rates and equipment rents.*

4. COBESTCO is programed for only one mode of productivity measurement.
5. COBESTCO is not programed to allow for easy expansion, reduction or alteration to data or to procedures.
6. COBESTCO is not programed to accept any size of project.
7. COBESTCO is not programed to allow for the computer-based generation of combinations of entities resulting in an acceptable product.

Certainly, other limitations also exist; however, these are sufficient for the conclusion which follows. This conclusion is that the detail per se is the essence of the success of the process. The success in COBESTCO is due to its ability to treat detail and its failure is due to the vice-versa.

In a sense these two conclusions lead to a paradox: (1) Detail is so complex that performance standards must be used and thereby neglect detail per se; and (2) detail per se must be treated directly. However, rather than a source of paradox, these conclusions can be the basis for recommendation for mode of operation: several organizations must combine in a coordinated joint effort to implement an automated estimating system for precoordinated building. Each organization is to represent a specialty, viz, manufacturers, computer manufacturers, architects, etc. and its needs—present and future. One organization would serve as the coordinator; i.e., the integrator, of this team of specialists. This organization for implementation would be in 1:1 correspondence with the utility and growth of the automated estimating procedure; this organization would give complete recognition to the import and complexity of the detail in such a system.

Finally, it can be concluded from this presentation that an industrywide automated cost estimating procedure for precoordinated building wherein data and programs can be interchanged with ease, is considered possible. However, the standards to accomplish this feat rest in approach (or process) and not in standardized components and practices.

```
115     LANDSCAPE A.REMOVE EXCESS DIRT
115.10    8510.80  FRONTENDLOADER. EQU 70 $/DAY. LAB 4.65 $/HR. 1 DAY **
115.20    8510.85  TRUCK.OF MATER..EQU 50 $/DAY. LAB 3.40 $/HR. 1 DAY **
115.30    8510.90  LABOURERS         2 EA.        LAB 3.25 $/HR. 1 DAY **
P       8500    LANDSCAPING
END
```

```
 AUTOMATED QUANTITY TAKE-OFF

C       FROST WALL AT THREE SIDES OF BLDG.
DIM     1     WALL       1    L 91.2     T 0.5     H 3.0
DIM     2     WALL       1    L 28.3     T 0.5     H 3.0
DIM     3     WALL       1    L 76.2     T 0.5     H 3.0
DIM     4     WALL       1    L 15.0     T 0.67    H 3.5
DIM     5     WALL       2    L 12.0     T 0.67    H 3.5
DIS     5     50.20      AREA
DIS     5     50.45      VOLUMN
C
C       4 BURRIED COLUMNS
DIM     1     COLUMN     4    D 1.0    H 9.8
DIS     1     50.15      LENGTH
DIS     1     50.40      VOLUMN

C       10 PIERS OF TWO DIFFERENT TYPES
DIM     1     COLUMN     6    L 3.0    T 3.0    H 0.5
DIM     2     COLUMN     6    L 2.0    T 2.0    H 4.5
DIM     3     COLUMN     4    L 2.0    T 2.0    H 3.5
DIS     3     50.10      AREA
DIS     3     50.45      VOLUMN
DIS     9     50.50      AREA

C       FOOTING FOR SHED GROUND WALLS
DIM     1     FTING      1    L 15.0    W 1.5    T 1.0
DIM     2     FTING      2    L 12.0    W 1.5    T 1.0

C       SPREAD FUNDAMENTS OF COLUMNS
DIM     3     FTING               4    L 4.67    W 4.67    T 0.5
DIM     4     FTING      ADDV   5.33   L 1.5     T 1.5     H 1.5
DIM     5     FTING      ADDV   16     B 1.5     H 1.5     L 1.67
DIS     5     50.05      PERIM
DIS     5     50.35      VOLUMN
```

FIGURE 11.—*Automated quantity takeoff.*

CPM-Network for Example Project: Small Industrial Building
(CPM-Network is given in "circle-notation")

7Da

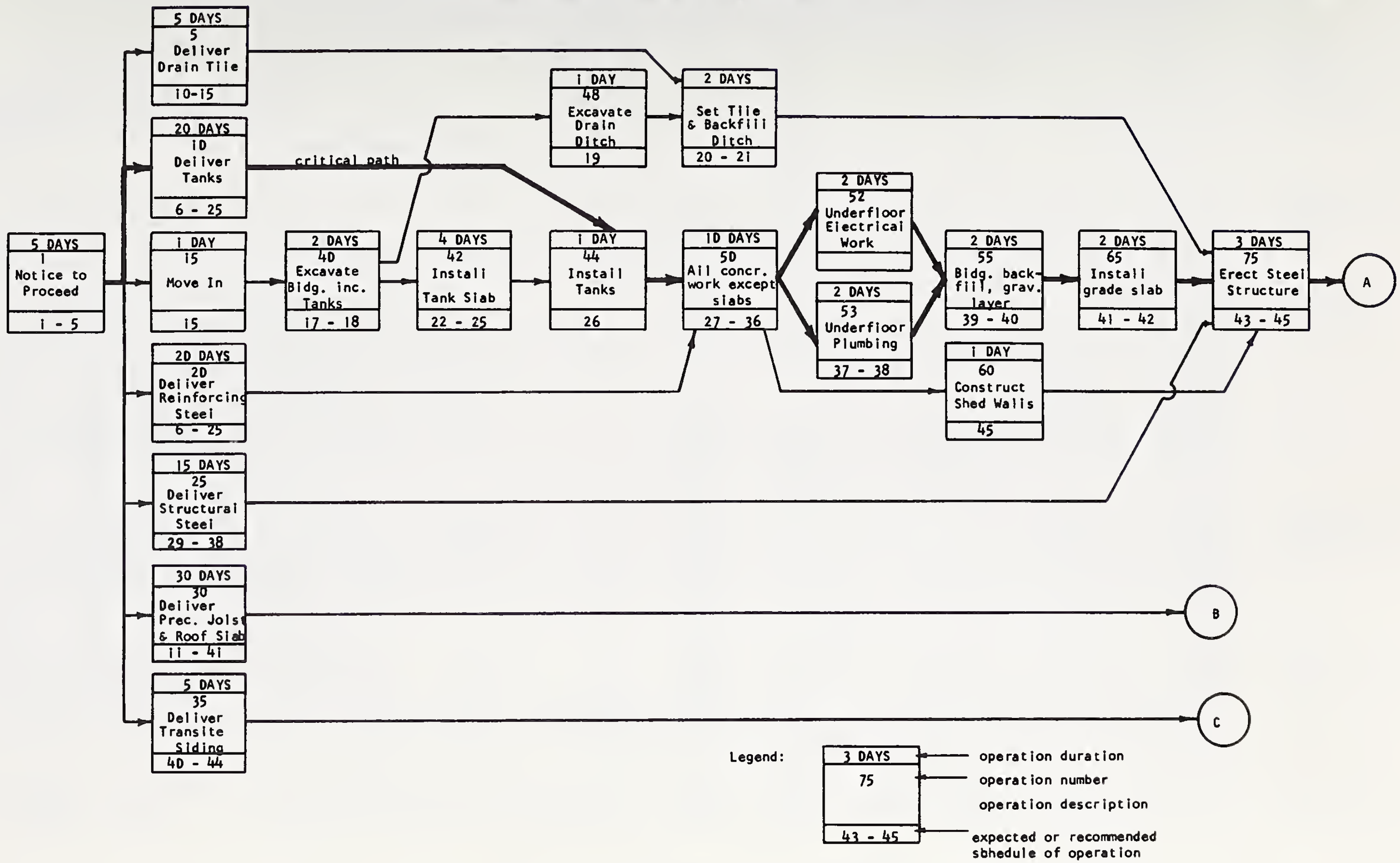


FIGURE 12—*CPM-Network for example project: Small industrial building (CPM-Network is given in "circle-notation)".*

NAME OF PROJECT - AEG ADDITION
DESCRIPTION - INDUSTR.BLDG
LOCATION - DRESDEN/NORD



JANUARY 21, 1965

DETAILED ESTIMATE - ORDERED BY OPERATIONS

| OPER-ATION | COST ACCOUNT | DATE | DESCRIPTION OF TYPE OF WORK | SUPPL. | QUANTITY | DURA-TION | LABOUR COST | EQUIPM. COST | MATERIAL COST | COST OF SUBL.WK. | TOTAL COST | LEV. | EFF. | OVT. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | | | EXCAVATION FOR BLDG.AND TANKS | | .0 | | 563 $ | 440 $ | 0 $ | 0 $ | 1003 $ | | | |
| .10 | 450.05 | NOV.64 | 1/2 CY - BACKHOE | BLDG. | 680.0 CY | 16 HRS | 250 $ | 120 $ | 0 $ | 0 $ | 370 $ | 1.0 | 1.0 | 0 |
| .20 | 450.10 | DEC.64 | ADD. HANDEXCAVAT. | BLDG. | 50.0 CY | 15 HRS | 146 $ | 0 $ | 0 $ | 0 $ | 146 $ | 3.0 | .9 | 0 |
| .30 | 470.15 | SEP.64 | 6-CY TRUCK | BLDG. | .0 | 16 HRS | 109 $ | 320 $ | 0 $ | 0 $ | 429 $ | 2.0 | 1.0 | 0 |
| .40 | 450.85 | | LABOUR FOREMAN | | .0 | 16 HRS | 58 $ | 0 $ | 0 $ | 0 $ | 58 $ | 1.0 | 1.0 | 0 |
| 42 | | | INSTALL TANK SLAB | | .0 | | 124 $ | 108 $ | 213 $ | 0 $ | 445 $ | | | |
| .10 | 1150.02 | SEP.64 | FORMS 1 BOARD DEEP | TK.SL. | 120.0 FT | 5 HRS | 34 $ | 0 $ | 30 $ | 0 $ | 64 $ | 1.0 | 1.0 | 0 |
| .20 | 1260.05 | OCT.64 | 6*6-NO.4 58LB/SQ. | TK.SL. | 3.0 EA | 1 HRS | 9 $ | 0 $ | 21 $ | 0 $ | 29 $ | 1.0 | .9 | 0 |
| .30 | 1021.14 | DEC.64 | GRADE SLABS | TK.SL. | 9.0 CY | 1 HRS | 14 $ | 8 $ | 162 $ | 0 $ | 184 $ | 1.0 | 1.0 | 0 |
| .40 | 9010.05 | DEC.64 | SELFPROP.CRANE 1CY | TK.SL. | .0 | 8 HRS | 68 $ | 100 $ | 0 $ | 0 $ | 168 $ | 1.0 | 1.0 | 0 |
| 44 | | | INSTALLATION OF TANKS | | .0 | | 188 $ | 100 $ | 2250 $ | 0 $ | 2538 $ | | | |
| .10 | 2610.85 | | | | .0 | 8 HRS | 120 $ | 0 $ | 2250 $ | 0 $ | 2370 $ | 1.0 | 1.0 | 0 |
| .20 | 9010.05 | DEC.64 | SELFPROP.CRANE 1CY | TANKS | .0 | 8 HRS | 68 $ | 100 $ | 0 $ | 0 $ | 168 $ | 1.0 | 1.0 | 0 |
| 48 | | | EXCAVATION OF DRAIN DITCH | | .0 | | 77 $ | 60 $ | 0 $ | 0 $ | 137 $ | | | |
| .10 | 451.15 | SEP.64 | DITCH TILL D=5 FT | | 180.0 CY | 4 HRS | 48 $ | 60 $ | 0 $ | 0 $ | 108 $ | 1.0 | 1.0 | 0 |
| .20 | 451.85 | | LABOUR FOREMAN | | .0 | 8 HRS | 29 $ | 0 $ | 0 $ | 0 $ | 29 $ | 1.0 | 1.0 | 0 |
| 49 | | | SET TILE AND BACKFILL DITCH | | .0 | | 167 $ | 67 $ | 550 $ | 0 $ | 783 $ | | | |
| .10 | 860.85 | | | | 1000.0 FT | 8 HRS | 80 $ | 0 $ | 550 $ | 0 $ | 630 $ | 1.0 | 1.0 | 0 |
| .20 | 460.70 | MAY 64 | BACKFILL W/GRADER | DRAIN | 200.0 CY | 8 HRS | 87 $ | 67 $ | 0 $ | 0 $ | 153 $ | 1.0 | 1.0 | 0 |
| 50 | | | ALL CONCR.WORK EXCEPT SLABS | | .0 | | 1953 $ | 624 $ | 1711 $ | 0 $ | 4288 $ | | | |
| .05 | 1150.02 | SEP.64 | FORMS 1 BOARD DEEP FTING | | 101.7 FT | 6 HRS | 46 $ | 0 $ | 41 $ | 0 $ | 87 $ | 1.0 | 1.0 | 0 |
| .10 | 1150.05 | MAY 64 | FORM SMALL PIERS | | 364.0 SF | 11 HRS | 175 $ | 0 $ | 73 $ | 0 $ | 248 $ | 1.0 | .9 | 0 |
| .15 | 1151.85 | | COLUMN | | 39.2 FT | 0 HRS | 33 $ | 0 $ | 27 $ | 0 $ | 60 $ | 1.0 | .6 | 0 |
| .20 | 1150.07 | DEC.64 | FORM FROST WALLS | | 1447.2 SF | 17 HRS | 429 $ | 0 $ | 217 $ | 0 $ | 646 $ | 1.5 | 1.0 | 0 |
| .25 | 1220.10 | DEC.64 | NO.6, DEFORMED | | 9100.0 LB | 0 HRS | 227 $ | 0 $ | 758 $ | 0 $ | 985 $ | 1.0 | 1.0 | 0 |
| .30 | 1260.05 | OCT.64 | 6*6-NO.4 58LB/SQ. | WALL | 11.0 EA | 5 HRS | 32 $ | 0 $ | 75 $ | 0 $ | 108 $ | 1.0 | .9 | 0 |
| .35 | 1021.15 | DEC.64 | NON-REINF.FOOTINGS | | 5.6 CY | 2 HRS | 31 $ | 8 $ | 100 $ | 0 $ | 139 $ | 1.0 | .6 | 0 |
| .40 | 1021.20 | DEC.64 | ROUND COLUMNS | | 1.1 CY | 1 HRS | 10 $ | 8 $ | 21 $ | 0 $ | 39 $ | 1.0 | .5 | 0 |
| .45 | 1021.17 | DEC.64 | WALLS AND PIERS | | 21.3 CY | 7 HRS | 97 $ | 8 $ | 384 $ | 0 $ | 489 $ | 1.0 | .9 | 0 |
| .50 | 1160.15 | OKT.64 | STRIP AND CLEAN F. | | 1934.4 SF | 6 HRS | 127 $ | 0 $ | 0 $ | 0 $ | 127 $ | 1.0 | 1.0 | 0 |

FIGURE 13.—*Detailed estimate—ordered by operations.*

NAME OF PROJECT - AEG ADDITION
DESCRIPTION - INDUSTR.BLDG
LOCATION - DRESDEN/NORD

PAGE 1 OF OUTPUT 3

JANUARY 2[illegible], 1955

SUMMARY OF THE ESTIMATE - ORDERED BY OPERATIONS

| OPER-ATION | DESCRIPTION OF OPERATION | LABOUR COST | EQUIPM. COST | MATERIAL COST | COST OF SUBLET WORK | TOTAL COST |
|---|---|---|---|---|---|---|
| 40 | EXCAVATION FOR BLDG.AND TANKS | 563 $ | 440 $ | 0 $ | 0 $ | 1003 $ |
| 42 | INSTALL TANK SLAB | 124 $ | 108 $ | 213 $ | 0 $ | 445 $ |
| 44 | INSTALLATION OF TANKS | 188 $ | 100 $ | 2250 $ | 0 $ | 2538 $ |
| 48 | EXCAVATION OF DRAIN DITCH | 77 $ | 60 $ | 0 $ | 0 $ | 137 $ |
| 49 | SET TILE AND BACKFILL DITCH | 167 $ | 67 $ | 550 $ | 0 $ | 783 $ |
| 50 | ALL CONCR.WORK EXCEPT SLABS | 1953 $ | 624 $ | 1711 $ | 0 $ | 4288 $ |
| 52 | UNDERFLOOR ELECTRICAL WORK | 0 $ | 0 $ | 0 $ | 375 $ | 375 $ |
| 53 | UNDERFLOOR PLUMBING | 0 $ | 0 $ | 0 $ | 600 $ | 600 $ |
| 55 | BACKFILL BLDG.AND PLACE GRAVEL | 379 $ | 241 $ | 100 $ | 0 $ | 720 $ |
| 60 | CONSTRUCT SHED WALLS | 175 $ | 0 $ | 90 $ | 0 $ | 265 $ |
| 65 | INSTALL GRADE SLAB | 300 $ | 108 $ | 1194 $ | 0 $ | 1602 $ |
| 75 | ERECT STEEL STRUCTURE | 889 $ | 400 $ | 4250 $ | 0 $ | 5539 $ |
| 80 | INSTALL PREC.CONCR.ROOF SLABS | 619 $ | 200 $ | 94 $ | 0 $ | 913 $ |
| 85 | ELECTRICAL WORK | 0 $ | 0 $ | 0 $ | 2000 $ | 2000 $ |
| 90 | PLUMBING | 0 $ | 0 $ | 0 $ | 2000 $ | 2000 $ |
| 95 | UNIT HEATERS AND NECESS.DUCTS | 0 $ | 0 $ | 0 $ | 2800 $ | 2800 $ |
| 98 | MACHINE TROWEL FINISH OF FLOOR | 257 $ | 15 $ | 0 $ | 0 $ | 272 $ |
| 100 | INSTALL TRANSITE SIDING | 855 $ | 100 $ | 1575 $ | 0 $ | 2530 $ |
| 105 | PAVE SITE | 0 $ | 0 $ | 0 $ | 3518 $ | 3518 $ |
| 110 | TAR ROOF,DOWNSPROUTS,GUTTER | 0 $ | 0 $ | 0 $ | 1411 $ | 1411 $ |
| 115 | LANDSCAPE A.REMOVE EXCESS DIRT | 90 $ | 120 $ | 0 $ | 0 $ | 210 $ |
| 120 | INSTALL METAL DOORS | 66 $ | 0 $ | 313 $ | 0 $ | 379 $ |
| 125 | OVERHEAD DOOR | 0 $ | 0 $ | 0 $ | 1425 $ | 1425 $ |
| 200 | PROJECT OVERHEAD | 1133 $ | 908 $ | 0 $ | 0 $ | 2891 $ |
| | | 7836 $ | 3491 $ | 12339 $ | 14129 $ | 38645 $ |

FIGURE 14.—*Summary of the estimate—ordered by operations.*

| COST ACCOUNT | OPER-ATION | DATE | TYPE OF WORK | QUANTITY | LABOUR COST | EQUIPM. COST | MATER. COST | COST OF SUBL.WK. | TOTAL COST | TOTAL COST PER UNIT |
|---|---|---|---|---|---|---|---|---|---|---|
| 1150 | | | WOODEN FORMWORK FOR BLDG. | | 1029 $ | 0 $ | 427 $ | 0 $ | 1455 $ | |
| .02 | 42.10 | SEP.64 | FORMS 1 BOARD DEEP TK.SL. | 120.0 FT | 34 $ | 0 $ | 30 $ | 0 $ | 64 $ | .535 $/FT |
| .02 | 50.05 | SEP.64 | FORMS 1 BOARD DEEP FTING | 161.7 FT | 46 $ | 0 $ | 40 $ | 0 $ | 87 $ | .535 $/FT |
| .02 | 65.10 | SEP.64 | FORMS 1 BOARD DEEP GR.SL. | 265.0 FT | 76 $ | 0 $ | 66 $ | 0 $ | 142 $ | .535 $/FT |
| .05 | 50.10 | MAY 64 | FORM SMALL PIERS | 364.0 SF | 175 $ | 0 $ | 73 $ | 0 $ | 248 $ | .681 $/SF |
| .07 | 50.20 | DEC.64 | FORM FROST WALLS | 1447.2 SF | 429 $ | 0 $ | 217 $ | 0 $ | 646 $ | .447 $/SF |
| .95 | 50.60 | | CARPENTER FOREMAN | | 269 $ | 0 $ | 0 $ | 0 $ | 269 $ | |
| 1151 | | | FIBER TUBE FORMS | 39.2 FT | 33 $ | 0 $ | 27 $ | 0 $ | 60 $ | |
| .85 | 50.15 | | COLUMN | 39.2 FT | 33 $ | 0 $ | 27 $ | 0 $ | 60 $ | 1.533 $/FT |
| 1160 | | | STRIP AND CURE CONCRETE | | 197 $ | 0 $ | 15 $ | 0 $ | 212 $ | |
| .15 | 50.50 | OCT.64 | STRIP AND CLEAN F. | 1934.4 SF | 127 $ | 0 $ | 0 $ | 0 $ | 127 $ | .066 $/SF |
| .85 | 50.55 | | CURE WITH WET BURL AB | | 70 $ | 0 $ | 15 $ | 0 $ | 85 $ | |
| 1220 | | | PLACE LIGHT BAR REINFORCMENT | 9100.0 LB | 227 $ | 0 $ | 758 $ | 0 $ | 985 $ | |
| .10 | 50.25 | DEC.64 | NO.6, DEFORMED | 9100.0 LB | 227 $ | 0 $ | 758 $ | 0 $ | 985 $ | .108 $/LB |
| 1260 | | | PLACE WIRE MESH | 42.0 EA | 115 $ | 0 $ | 288 $ | 0 $ | 403 $ | |
| .05 | 42.20 | OCT.64 | 6*6-NO.4 58LB/SQ. TK.SL. | 3.0 EA | 9 $ | 0 $ | 21 $ | 0 $ | 29 $ | 9.794 $/EA |
| .05 | 50.30 | OCT.64 | 6*6-NO.4 58LB/SQ. WALL | 11.0 EA | 32 $ | 0 $ | 75 $ | 0 $ | 108 $ | 9.794 $/EA |
| .05 | 65.20 | OCT.64 | 6*6-NO.4 58LB/SQ. GR.SL. | 28.0 EA | 74 $ | 0 $ | 192 $ | 0 $ | 266 $ | 9.500 $/EA |
| 1452 | | | PRECAST ROOF ELEMENTS | | 484 $ | 0 $ | 94 $ | 0 $ | 578 $ | |
| .10 | 80.10 | DEC.64 | MEDIUM CONCR.DECK M.BLDG | 2700.0 SF | 364 $ | 0 $ | 0 $ | 0 $ | 364 $ | .135 $/SF |
| .10 | 80.20 | DEC.64 | MEDIUM CONCR.DECK SHED | 180.0 SF | 24 $ | 0 $ | 0 $ | 0 $ | 24 $ | .135 $/SF |
| .80 | 80.30 | | PREC.JOIST | 2.0 EA | 12 $ | 0 $ | 94 $ | 0 $ | 106 $ | 53.000 $/EA |
| .85 | 80.40 | | BRICKL.FOREMAN | | 83 $ | 0 $ | 0 $ | 0 $ | 83 $ | |
| 1480 | | | CONCRETE BLOCK | | 175 $ | 0 $ | 90 $ | 0 $ | 265 $ | |
| .30 | 60.10 | OCT.64 | CONCR.BLOCK 4*8*16 SHED | 300.0 SF | 133 $ | 0 $ | 90 $ | 0 $ | 223 $ | .744 $/SF |
| .90 | 60.30 | | BRICKL.FOREMAN | | 42 $ | 0 $ | 0 $ | 0 $ | 42 $ | |
| 2510 | | | STEEL ERECT.IN MILL-TYPE BLDG | 50900.0 LB | 686 $ | 100 $ | 4250 $ | 0 $ | 5036 $ | |
| .05 | 75.10 | DEC.64 | MEDIUM FRAME | 50900.0 LB | 686 $ | 100 $ | 4250 $ | 0 $ | 5036 $ | .099 $/LB |

FIGURE 15.—*Detailed estimate—ordered by cost accounts.*

NAME OF PROJECT - AEG ADDITION
DESCRIPTION - INDUSTR.BLDG
LOCATION - CRESCEN/NORD

RECAPITULATION SHEET OF THE ESTIMATE

| WORK CLASS | TYPE OF WORK | LABOUR COST | EQUIPM. COST | MATERIAL COST | COST OF SUBL.WK. | TOTAL COST |
|---|---|---|---|---|---|---|
| 400 | EXCAVATION, BACKFILL, HAULING | 1106 $ | 808 $ | 100 $ | 0 $ | 2013 $ |
| 800 | DRAINAGE | 80 $ | 0 $ | 550 $ | 0 $ | 630 $ |
| 1000 | CONCRETE WORK | 492 $ | 55 $ | 1603 $ | 0 $ | 2150 $ |
| 1100 | CONCRETE FORMWORK | 1259 $ | 0 $ | 469 $ | 0 $ | 1728 $ |
| 1200 | REINFORCING STEEL | 343 $ | 0 $ | 1046 $ | 0 $ | 1389 $ |
| 1400 | PRECAST CONCR. AND CONCR.BLOCK | 659 $ | 0 $ | 184 $ | 0 $ | 843 $ |
| 2500 | STRUCTURAL STEEL | 686 $ | 100 $ | 4250 $ | 0 $ | 5036 $ |
| 2600 | TANKS AND BOILERS | 120 $ | 0 $ | 2250 $ | 0 $ | 2370 $ |
| 2700 | METAL DOORS AND WINDOWS | 66 $ | 0 $ | 313 $ | 1425 $ | 1804 $ |
| 3000 | ROOFING AND SHEET METAL | 0 $ | 0 $ | 0 $ | 1411 $ | 1411 $ |
| 3100 | SIDINGS | 787 $ | 0 $ | 1575 $ | 0 $ | 2362 $ |
| 4000 | PLUMBING | 0 $ | 0 $ | 0 $ | 2600 $ | 2600 $ |
| 4200 | HEATING AND VENTILATION | 0 $ | 0 $ | 0 $ | 2800 $ | 2800 $ |
| 4400 | ELECTRICAL WORK | 0 $ | 0 $ | 0 $ | 2375 $ | 2375 $ |
| 8000 | SITE PAVING | 0 $ | 0 $ | 0 $ | 3518 $ | 3518 $ |
| 8500 | LANDSCAPING | 90 $ | 120 $ | 0 $ | 0 $ | 210 $ |
| 9000 | EQUIPMENT EXPENSES | 1014 $ | 2208 $ | 0 $ | 0 $ | 3222 $ |
| 10000 | OVERHEAD | 1133 $ | 200 $ | 0 $ | 0 $ | 2183 $ |
| | | 7836 $ | 3491 $ | 12339 $ | 14129 $ | 38645 $ |

FIGURE 16.—*Recapitulation sheet of the estimate.*

# Precoordination Requirements for Computerized Specifications

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This discussion concentrates on three general topics. First, specification as a communication media; second, the automation of specifications; and third, the precoordination requirements for specifications automation.

Key words: Automated specification; communication media; precoordination.

## 1. SPECIFICATIONS AS A COMMUNICATIONS MEDIA

Before any discussion can have true meaning it is necessary to place the discussion in context. Each of us is biased by his background. My background is biased by the research that we do in the Facilities and Housing Research Department of Stanford Research Institute. Like most of you, we are deeply involved with our national construction system. In particular, we are looking at the delivery of a complete product; i.e.—a building, structure, or a house—to its new user. We do not stop at the point of delivery however, but are looking at the life cycle of the facility including its maintenance and operating cost and the cost of managing and financing it over its life cycle. We are involved in housing research from the standpoint of the total housing system. We look at the supply of housing as a consumption unit rather than as a singular investment. We are actively engaged in the housing demonstration field. Along with Olin Mathieson Corp., Northern Natural Gas and Jonathan Development Corp., we are partners in the Jonathan Housing Corp., which will be demonstrating housing in the new town of Jonathan, Minn. The purpose of this project is to demonstrate new concepts in housing and the housing system. The thrust of our research is to change the current housing system to meet the needs of the future. Hopefully we can make it possible for all of our people to be properly housed at a reasonable cost. To a major degree, our group in the Washington area is involved in the management of the design-construction process and in the related information handling for both the management and technical phases of design and construction. Because specifications are one of the primary construction information exchange mechanisms we have become involved in the specifications process.

Figure 1 is a pictorial representation of the delivery system for construction. It appears on the surface to be similar to many other product delivery systems. Those of us who are familiar with the process recognize that we start with requirements which are generally not well stated and must work through a very laborious process involving many participants to reach the final end result. Because we are all familiar with the system, we know its frailities and its strengths and we can make it work. But all of us recognize that it is too often inefficient. These inefficiencies result in high costs, long delivery times, and facilities that are marginal within a few short years.

Figure 2 illustrates the type of participants involved in the design-construction process. To a large degree construction works on a cottage industry basis. Each one does his particular thing in the process (often in isolation), and then passes it on to the next participant. Redundancy is prevalent. For example, estimates are made by the owner, the architect, or engineer, perhaps a cost consultant, and certainly by all the contractors and subcontractors who are going to be involved in the project. In materials research we have another example of redundancy. The designer selects the products, perhaps very specifically. At this time it is the specifiers task to describe it generically hiding the specificity of the selected product. The contractor who is looking at the printed specifications to provide the product, again tries to satisfy the need, but under a different set of parameters, these being lowest cost, not best performance.

It is plain to see that what we have created is a tortuous path resulting in a process where only those interested in the legal side of the business are able to prosper. This system is such that everyone else is a protagonist and regardless of good intention is forced to play the game in accordance with the legal rules established.

The art of constructing and designing is a complex process and one which many have recognized the need to streamline and simplify. People in our profession have recognized this need for improvement and have attempted to search out automation devices that might be of assistance. One of the areas to receive attention for automation is the area of construction specifications.

## 2. THE AUTOMATION OF SPECIFICATIONS

In 1967 Stanford Research Institute was commissioned by the Construction Specifications Institute to do a survey on the state of the art of specification auto-

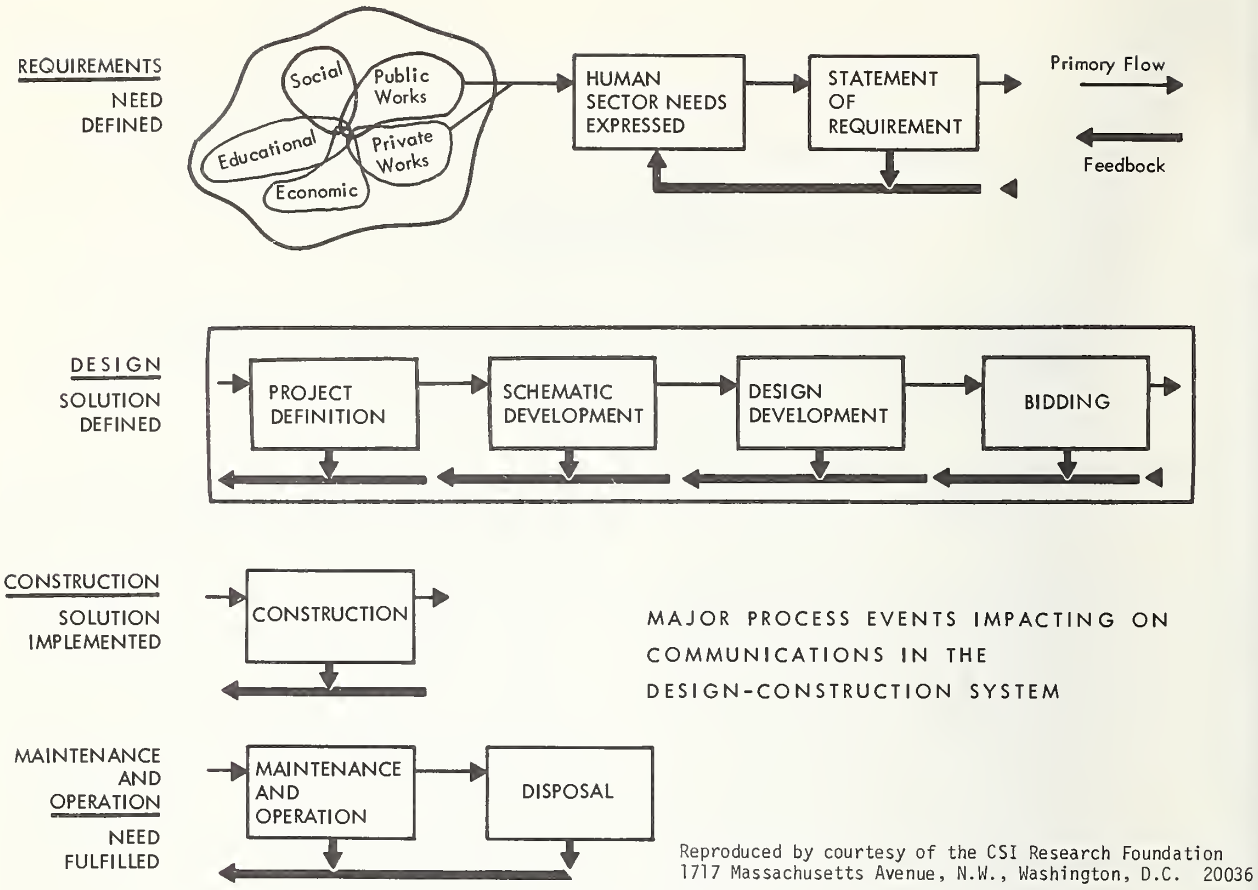



FIGURE 1.—*Major process events impacting on communications in the design-construction system.*

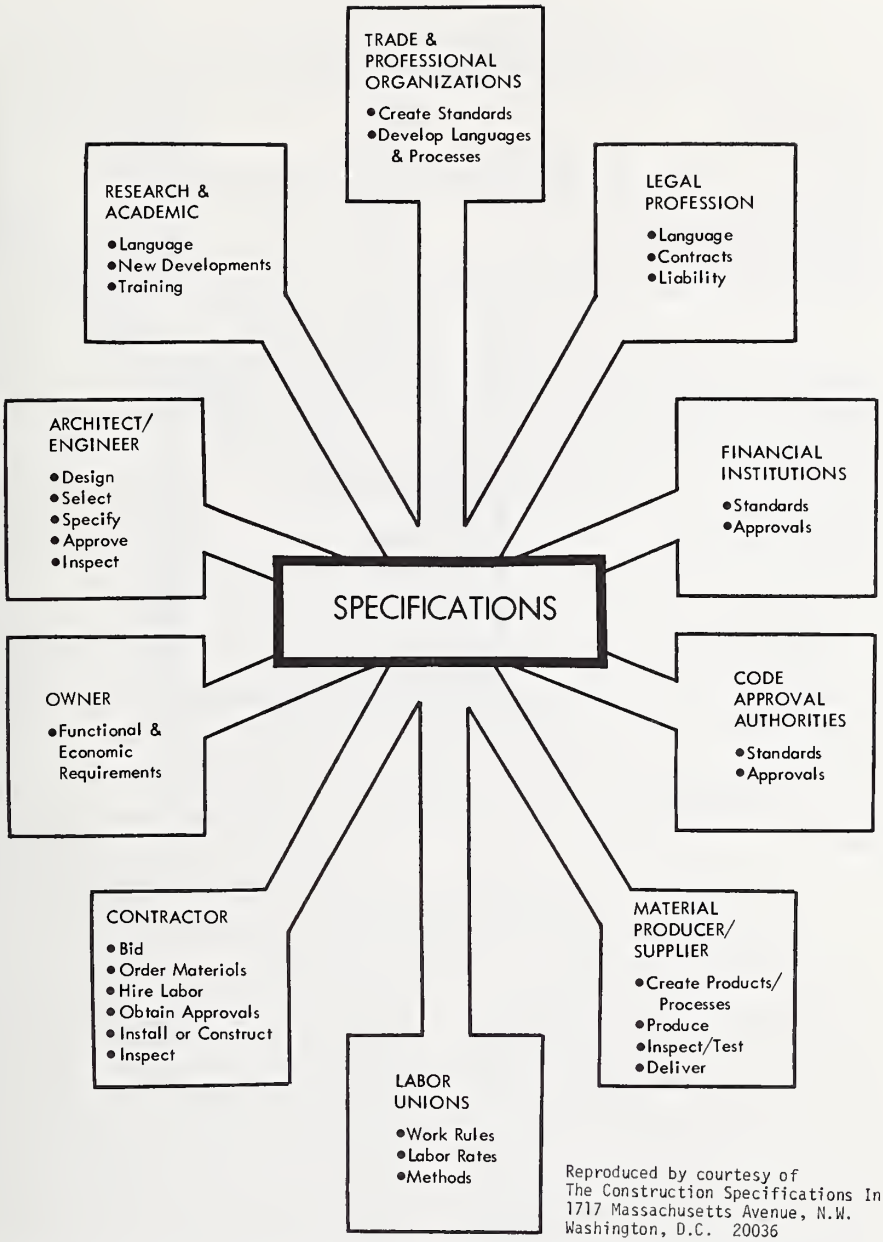
mation. In our survey findings which were printed by CSI in November 1967, we made the following points:

- Specifications are part of a very formal communications process.
- There are many initiators of the messages involved in the specifications process.
- Each of the receivers of these messages has to make an interpretation and hopefully these interpretations are in the same vein as the original message.
- That the system to be of value requires feedback. Feedback is now obtained in the terms of approvals for shop drawings and by inspection on site.
- The drawings provide visual expressions of structure geometry, while the specifications provide verbal descriptions of the materials with instructions on how to assemble these materials or to put them in place.
- That failure in these communications leads to delays, legal scrambles, extra cost, and could result in potential safety hazards either to the constructors or to the future occupants of the structure.
- The goal in any specification process has to be error-free communications, and communications with a minimum of extraneous noise.
- It was pointed out that automation can help in achieving these error-free communications. Automation can reduce error, could eliminate redundancy and certainly improve inefficiency.

The next question that faced us was to describe the state of the art. Just how can we measure it? Figure 3 provides a profile of the state of the art which identifies six levels of sophistication in automation, shown along the left hand side of the chart. We were also able to identify certain kinds of equipment which were in use to aid in automation. These are shown along the bottom of the chart. Through our samples we were able to determine that we were approximately in Level I or II for our existing "state of the art."

In Level I we are in a "cut and paste" type of operation. This is one in which the specifier is pulling from past job specifications or from new material and trying to assemble a new document. This type of work is fraught with danger, not only from clerical error, but in the pure sense of knowing that the material being incorporated is in fact the latest material available on the subject or process in question.

At Level II the process is much the same, but in

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**PRINCIPAL PARTICIPANTS IN THE SPECIFICATIONS COMMUNICATIONS PROCESS**

Source: Automated Specifications; A Research Study, CSI Document STD-1

FIGURE 2.—*Principal participants in the specifications communications process.*

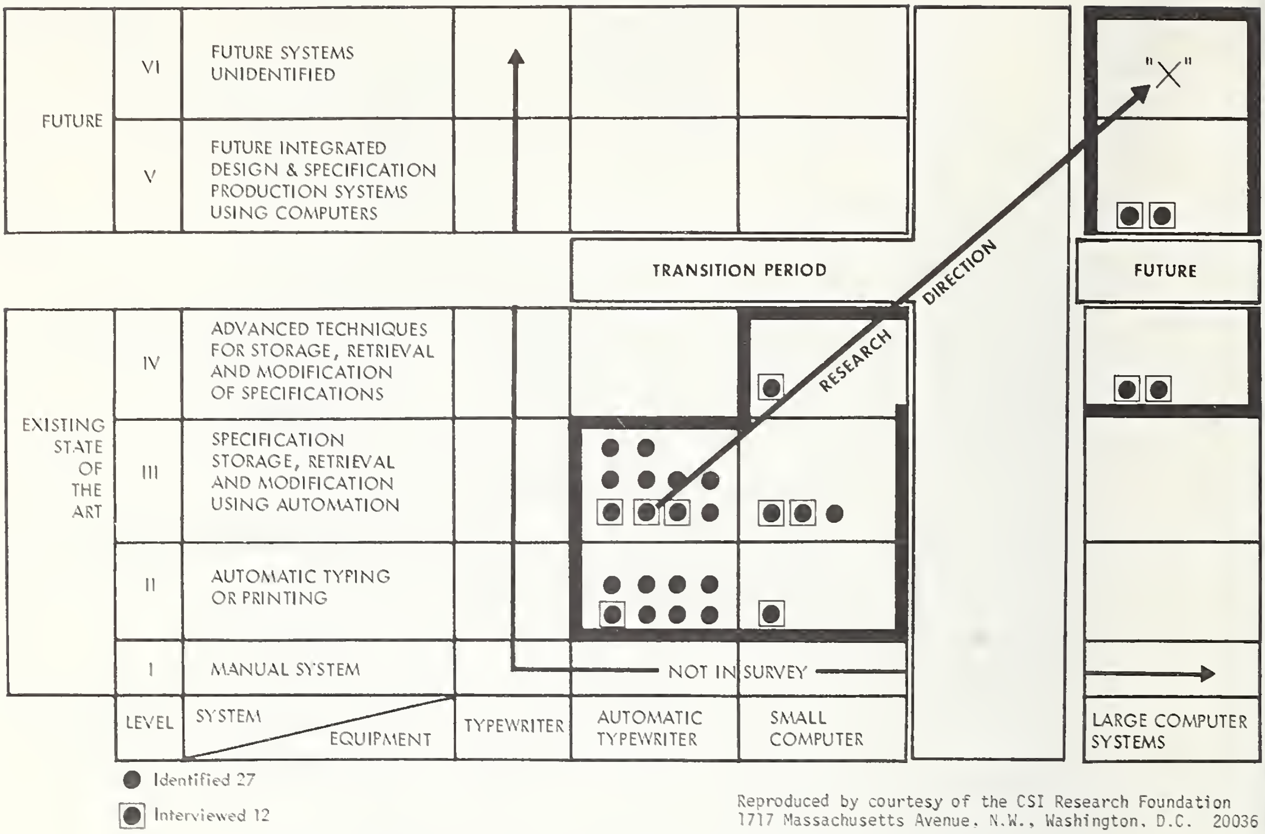


FIGURE 3.—*Research potential in the construction communications process.*

order to assist in the clerical functions of the operation an automatic typewriter or computer is introduced. Some savings in clerical time or effort are possible through this mechanism.

It is at Level II where the first elements of a good communications process are developed. At Level II a master specification is stored and then modified for each specific job specification. At Level II we have two phases. First, we must establish a master file. This file can be either on the basis of a master or guide specification. On a master specification we include as many of the alternatives as is possible and work in a "delete" mode. In a guide specification blanks are left which must be filled in. In a good guide specification the material for providing selections to fill in the blanks should be provided and in essence is merely a reversal in the clerical mode of a master specification.

In producing a specification at Level III the specifier selects (hopefully very early in the process) a job specification at the end of preliminary design. During the design proces he then brings the specification into the exact job framework needed and at the end of the design drawing stage the specification should be ready to be corrected and reprinted using the master file base.

Figure 4 is an example of the type of master specification that is necessary for a Level III system. This particular example was on an automatic typewriter system. As can be seen, it includes alternatives in order that the specifier have a choice for a selection for coverage and completeness. Second, it is set up to use a delete process to a maximum extent. Also it is possible to issue this type of specification very early in the design process. As can be seen in figure 4, the master must include notes to the user to assist in selection, to provide cross-references to other materials, and to give an indicatilon of firm (organizational) policy.

It needs to be pointed out that the specifiers role will change as automated specifications are introduced into practice. The specifier will spend more of his time on the updating of master specifications insuring that they are complete and current rather than in the production of individual job specifications. There are advantages, of course, to this type of system. It eliminates the need to build each job from scratch thereby reducing the typing time, clerical time, and most important, the professional time involved in writing specifications. It reduces errors as well as the time to produce the specification. It maintains consistency in language which would permit the firm to enjoy better communications

*SPEC NOTE: Drawings should designate yield requirements. Strike out non-applicable yield requirements below.*

| Designation | | Grade | Yield |
|---|---|---|---|
| a. | ASTM A 15: | structural | 33,000 |
| | | intermediate | 40,000 |
| | | hard | 50,000 |
| b. | ASTM A 16: | regular | 50,000 |
| | | special | 60,000 |
| c. | ASTM A 160: | plain structural | 33,000 |
| | | plain intermediate | 40,000 |
| | | plain hard | 50,000 |
| | | deformed structural | 33,000 |
| | | deformed intermediate | 40,000 |
| | | deformed hard | 50,000 |
| d. | ASTM A 431: | only one grade | 75,000 |
| e. | ASTM A 432: | only one grade | 60,000 |

20. Fabricated steel bar or rod mats for concrete reinforcement: conform to ASTM Designation A 184. Bars shall be as specified above, except that hard grades shall not be used for welded mats. At intersections, weld rods together to form rectangular grid.

21. Reinforcement wire: conform to ASTM Designation A 82.

22. Welded steel wire fabric: conform to ASTM Designation A 185.

23. Expansion joint fillers: conform to ASTM Designation D 1751; non-extruding, resilient, bituminous type.

*SPEC NOTE: Above type not to be used when polysulfide type, silicone type, urethane type, or similar non-bituminous materials will be used for final joint sealing. It is important to coordinate this with Calking and Sealing Section of the Specifications.*

24. Expansion joint fillers: conform to ASTM Designation D 1752, resilient, non-bituminous, Type _____ .

*SPEC NOTE: In space above, insert desired type number; Type I: PVC plastic, or sponge rubber; Type II: cork; Type III: self-expanding cork. Any of these may be used with all types of joint sealing materials. Type I is recommended. PVC plastic is available in soft and semi-rigid grades; semi-rigid is recommended.*

MASCO 367

EXAMPLE OF NOTES PREPARED FOR SPECIFIERS' USE.
(With permission, M. Davis Alexander, Master Systems Corporation, Dallas, Texas).

CONCRETE & CEM. FIN.
Master Specification
Page 5

FIGURE 4.—*Example of notes prepared for specifiers' use.*

with the contractors normally involved in their work. And it provides a consistent base for evaluation of the specification itself.

At this point it would be well to mention some of the cautions that must be observed in developing automated specifications. First, like any system that is to be used repetitively, it must be well planned. Second, it is necessary to budget for design and development of this system so that it can be produced in a reasonable fashion and at reasonable costs. Third, attention to proofing is necessary for every error will be repeated until it is caught. Level III systems are in use today in many offices and should be the standard for the industry at this point in time. Unfortunately, less than 20 percent of the design firms in the United States are using Level III specification systems.

The next level in sophistication is reachable today and has been attempted by a very few people. Level IV takes advantage of the capability of computers to aid in managing and improving the technical accuracy of the specification process. Level IV uses punched paper tape input where feasable so that there is a potential for a hard copy check of the information being entered into the data bank. Improved notes to the specifier are possible so that the job captain or project manager can write the specifications as he designs and selects his materials. The specifier consults and maintains the masters and in the overall, is thereby expanding his influence in design selection by providing a higher level of quality service. It is also possible to install fail-safe techniques in the system. For example, it is possible to link the floor-covering section with the concrete section to insure that the concrete finishes specified will be satisfactory for the floor coverings selected. It is also possible to install automatic spacing and pagination, the changing of page numbers, or the closing of the job file as is necessary. One can provide lists automatically indicating which shop drawings are required, what samples must be taken and what tests are involved. As part of this system it is possible to develop management feedback for the specification system itself. The feedback would tell management how often a specification has been used, how often it's been modified, and also provide a place to identify the sections which have caused field problems or failures.

The systems at Levels I thru IV that we have discussed, are feasible and possible today. The technology and hardware exists so that they may be part of the design and construction process. Their ready adoption should be assumed but, unfortunately, it has been delayed by the hesitancy of engineering and architectural professionals to accept the capabilities of automation to assist them. There seems to be an inbred fear of these systems in the minds of many. This is unfortunate and should be eliminated to the degree possible by widespread programs of education. Let's take a look now at the potentials of automation for tomorrow.

### 2.1 What About Tomorrow?

Referring back to figure 3, let's talk about Level V systems that are technologically feasible at this particular time. These Level V systems don't exist even in the laboratories today, but they can be with us by the 1980's. Why should we be optimistic that people who have failed to implement Level IV sysems will make a giant step into the Level V systems of the future? It appears to me that there are three major pressures for change. First, our urban problems cry for good engineering and architectural solutions that can be afforded. Second, in addition to our current, decaying physical plant requiring replacement, we are faced with tremendous population increases in the next two decades. These people must be housed and there must be a business and social structure provided for them, as it has been for us. The third thing is, that as we have developed in the past 60 years, technology has increased many times in terms of its availability and its degree of sophistication. There is no reason to think that this degree of technological advancement will stop at this particular time. We have good technology now —we will have better technology tomorrow.

For example, within the last 20 years, we have developed mathematical modeling and simulation techniques. We started from the point where we worked on very specific problems. We are now beginning to recognize certain general problem solutions for optimization, such as queuing and transportation problems. We have improved our prediction capability through simulation rather than using statistical forecasts. We are able to build a model of some part of the world as it might grow, rather than projecting it on a mathematical basis from past historical data. This gives us the ability to have a new awareness of changes in urban and environmental relationships that may develop. As a result of automation in communication technology we have a knowledge transfer capability that has never existed before. Better education, better communication, and an increasing ability to tackle problems that are multi-disciplinary in nature, offer increased capability in knowledge generation. In addition to increased knowledge we have better equipment. For example, in our systems engineering lab we have the equipment shown on the slide for man-machine interaction. This is fairly simple equipment utilizing a TV tube, an electric typewriter, and instead of the familiar light pen, a mechanism which we call "the mouse." The "mouse," like the light pen, generates an emission source on the face of the tube so that the user can identify a word, a phrase, a paragraph or sketch on the tube itself. Cost for equipment such as this is going down and we can handle text or visual material interchangeably, and it is even possible to go into color presentations. We have the ability to expand, contract, or rotate the display. We could, in effect, walk into or away from a simulated drawing of our particular building or structure; we could prepare animated studies to show the impact of our particular problem on a human scale.

It can be but a short time until these computer-aided tools are common-place in our design offices. To give you some idea of the feel for this type of man-machine interaction, we have developed a movie to demonstrate the text editing of a construction specification. This

particular movie was based on a CSI Guide specification and was handled completely by written or telephonic communication means in its development stages. Starting with little more than the knowledge that the text editor existed, it was possible to write a program that could be introduced into the machine via a letter. This specification demonstration has heen shown at the CSI convention in Denver in 1968 as well as to other audiences. The movie shows, without a doubt, that it is possible to quickly and effectively manipulate and change text-type information, checking it for its accuracy and maintaining it in a permanent file so that it is possible to use work reference rather than using numerical references to recover information. The machine will automatically seek the word or phrase designated and will provide from its reference libraries the source material as desired. It is possible to layer these reference files so that one may go from one reference file to another rather rapidly. The movie demonstrates that we have the hardware technology and the softwear technology necessary to edit texts similar to those used in specifications. The problem now, is to get this technology in a form that can be used by the design professionals across the United States.

One real problem is in the basic way that we approach design today. We do it intuitively through on-the-job, rather than formal training. Our ability to design is a result of largely an undocumented art. Figure 5 shows our profile specification automation on levels with a barrier indicated between IV and V on selection of materials. There is a serious problem in construction information handling. For example, today when we think of floor coverings that would be suitable for our design we think, perhaps, of asphalt tile or carpet and then proceed from that point. If we were really designing in a performance vein, we would be starting with the performance desired for that particular floor surface. We would describe its acoustic qualities, or its visual qualities, or its properties related to durability. From these performance statements we would enter a file and seek out the materials which would satisfy our needs. In practice today, we do the reverse. We select the material and then determine whether the qualities are suitable for the applications intended, perhaps overlooking many other choices which would be just as suitable.

Of course, to do this type of performance seeking in our design process, we need an information system on materials. One that relates to performance and is current, and one that would contain cost data so that our comparisons and selections would be based on all

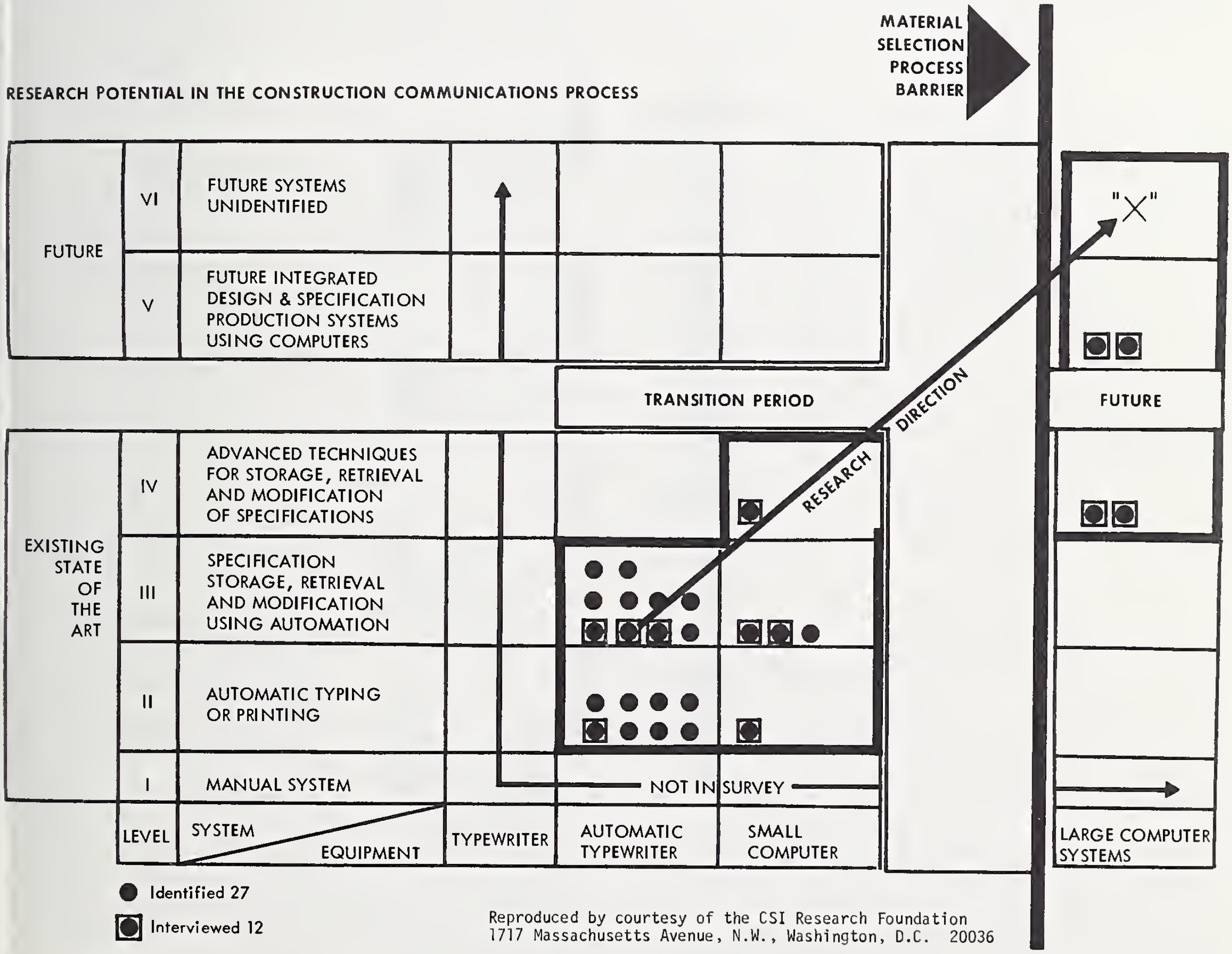


FIGURE 5.—*Research potential in the construction communications process.*

of the necessary factors involved. Figure 6 shows a feasible Level V machine configuration. What is envisioned is a complete data bank for construction information that can be tapped by anyone in the process. Basically, the system would operate on the premise that no data would be transmitted until it was needed by the particular user. Further, the machine would search and retrieve in a format suited to the particular users' demands. This seems like a far-reaching system that is not obtainable today. Such is not really the case. Stanford Research Institute is participating in the development of a computer network which will extend from Utah to Southern California, to transmit visual as well as digital data and which will utilize shared information storage systems. By the time the construction industry is ready for a national system, the specific technology will be available to permit us to economically use the nationwide construction system that we need. Again, it must be stated that the technology of communications and of automation is not the stumbling block to progress in construction communications. Based on the existing state of the art in construction communications and on the technology that will be available in the future, let us examine then the requirements for precoordination in the specifications automation area.

## 3. PRECOORDINATION REQUIREMENTS FOR SPECIFICATIONS AUTOMATION

Based on our discussion so far, it could seem that we do not have any sort of national standards for specifications today that would assist us in our process of precoordination. Such, of course, is not the case. We have a number of tools available or in the process of being developed for the very near future. The CSI format arranges construction documents into four major groupings; bidding requirements, contract forms, general conditions, and specifications. Specifications are further divided into 16 standard divisions. The Uniform System which has been adopted and promulgated jointly by CSI, AIA, NSPE, AGC, ASLA, and the Counsel of Mechanical Speciality Contracting Industries carried the CSI format a step further providing systems for construction data filing and cost accounting. In the area of construction materials information a system called "SPEC Data" provides a means of uniformly portraying construction materials information in ten standard categories. Included in this system is a means of conformity review. Although the validity of the data may still be questioned, at least the user of the data does not have to search through

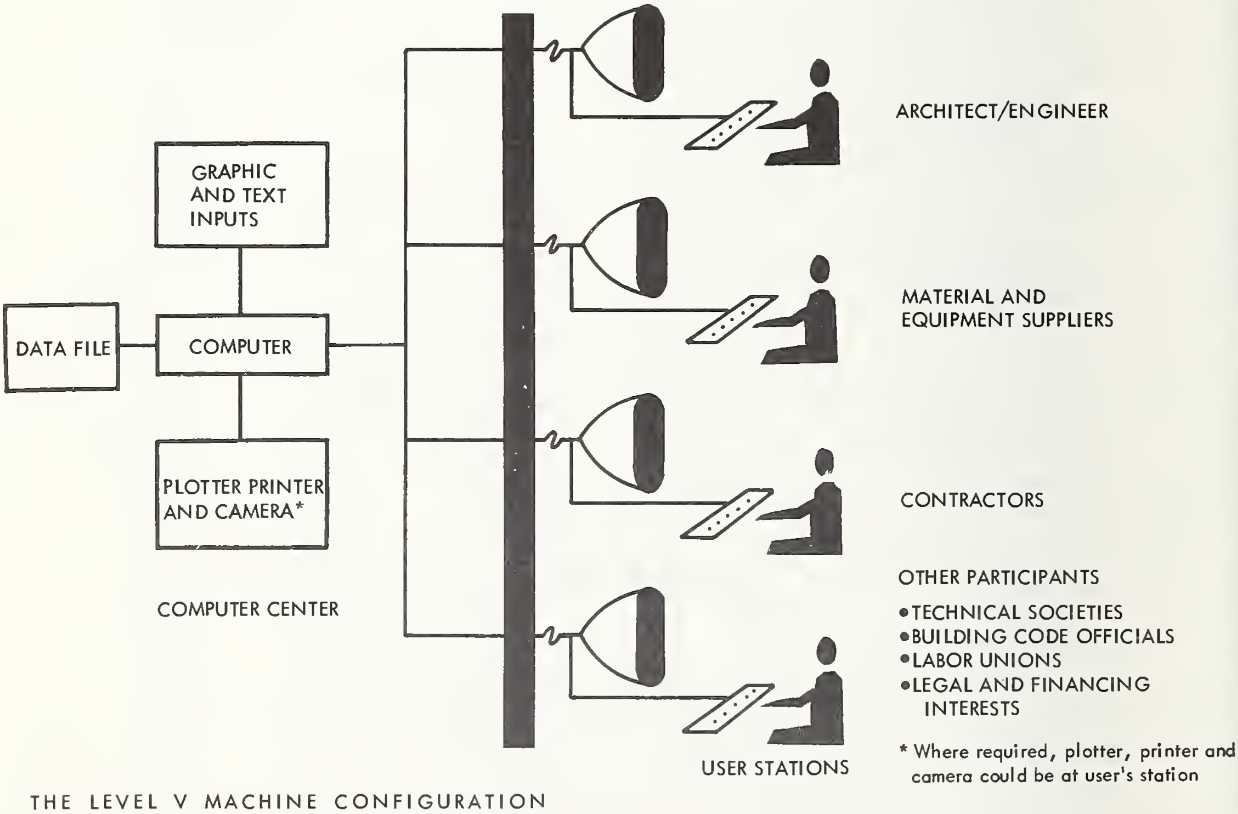


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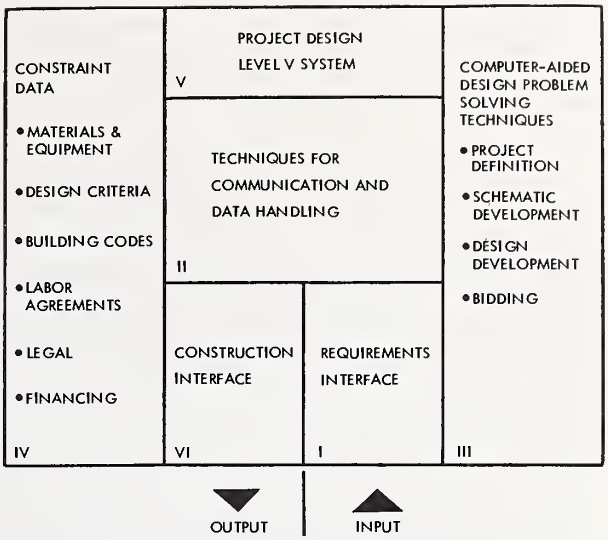
FIGURE 6.—*The level V machine configuration.*

a thousand different formats to find the information he needs.

Due within a few months are the following additional aids. First, "SPEC Data II" which will provide a microfilm library of construction materials with a product parameter (or comparison) feature. This microfilm file will permit one to quickly review the various products that are available for a particular application and determine which ones best meet the problem at hand. The system is also such that it will suit various levels of practice from the very smallest to the largest in terms of equipment or equipment availability. The second system to come on the line in the near future will be the "Open-ended Specification System." On September 15, 1969, CSI announced the award of a research contract to Stanford Research Institute to develop an Open-ended Specification System. The Open-ended System to be developed should provide a nationwide opportunity for the individual design practitioner to obtain specification automation assistance through a local data processing service or bureau. The individual design firm equipped with even the rudiments of a basic master specification text will be able to store his specification text, modify and retrieve it, and produce a job tailored specification ready for print on an individual project. This Open-ended Specification System will provide architects, engineers, and specification consultants with a proven specification processing system.

A large number of the professional design firms are of relatively small size and therefore cannot support the cost of developing an automated specification system on an individual basis. On the other hand, the data processing service bureaus do not have the knowledge of construction design practice to permit them to develop such systems. With the CSI Research Foundation acting as the industry catalyst, Stanford Research Institute will develop a set of criteria for a nationwide specifications system. This single package will provide the data processing services with the specification for an automation system that will satisfy the needs of practically every designer. Regardless of his location, or the service bureau utilized, the designer will have to be acquainted with only one system, a system tailored to industry standards as they exist today. The time table for delivery of this Open-ended System is early in 1970 as of this particular time.




MAJOR AREAS INVOLVED IN THE DEVELOPMENT OF LEVEL V INTEGRATED DESIGN AND SPECIFICATION PRODUCTION SYSTEM

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FIGURE 7.—*Major areas involved in the development of level V integrated design and specification production system.*

## 4. PRECOORDINATION REQUIREMENTS FOR SYSTEMS OF THE FUTURE

Figure 7 indicates areas of development needed for the Level V Systems of the future. Standards are required in most every area of development. For example, in looking at the Requirement Interface we need to know what performance we are looking for in the particular facility under design. What functions need to be performed within the facility? How are we going to state these functional performance criteria?

In the area of Constraint Data there are three factors that come to mind immediately. We need an evaluation system for testing and certifying material performance. We need ways to express this performance in our various codes. What types of terms are we going to use in these code systems so that they will fit in our information systems of the future? In dealing with labor, we have to know what type of materials or assemblies will minimize labor problems if we are to design effectively.

Our Computer Aided Design Techniques will require software that is fast, simple, and self-correcting; softwear that will assure that there is no data loss; and certainly, softwear that is eonomical.

In the area of Communications and Data Handling is is apparent to everyone that time-sharing is a necessity. We will need central data banks both at regional and national levels. If we are to have these systems and these data banks, we have to know the following: who is going to maintain the system; who is going to control access; and how is it going to be financially supported?

In terms of the Level V Project Design, we have to know how we are going to work the process. In what terms are we going to permit man to use his creative and intuitive ability? How are we going to back up man's creative ability with the logic of machine search, storage, retrieval and computational capability?

Looking at the Construction Interface, one of the questions that comes up immediately is, do we produce drawings and specifications or do we just tap in a receiver at a factory or job site to the computer. We have to know how the contractor's role will change. How is the material supplier's role going to change? It is apparent that if we are going to optimize design, we certainly can't select or change materials after

optimization of the system without taking the risk of ruining the system. We may have to go to a process construction system where the owner buys the material and the contractor installs to the designer's specifications.

It is apparent that we can't get all of the answers to these questions in a single year. We can do it in 10 years if we get some significant research and development money focused on the problem. We spend $2 billion on annual automobile model changes. This year the Department of Housing and Urban Development for Operation Breakthrough is going to spend $15 million to attempt to improve housing for two hundred million people for many years into the future. There is something wrong with our set of construction industry priorities that permits this type of expenditure level to exist. It is apparent that we who live in and off the construction industry must get together and push, not just with words for progress, but for real research and development funds. Let's put our money where our mouths are. Industrialization of housing, offices and other institutional type buildings is going to come. We at Stanford Research Institute, are committed to making it happen in some form because it is necessary to fulfill our Nation's needs. We engineers and architects, contractors and building materials producers, either carve a place for ourselves in creating this new environment or like the blacksmith, we will get overtaken by changing technology.

The need for standards to permit vital information interchange was never so urgent. My thanks to the organizers of this program for their farsight in selection of the theme "Precoordination—The Basis for Industrialized Building." Unless industrywide standards are set and accepted, not only for materials, but for the communications we need in construction, we cannot expect to build enough shelter, much less the business and social structure required for our life style. Without such change, it is likely that the open system of design we now enjoy will fall, and closed systems will take over except for monumental work such as mausoleums and other common meeting places. I do not think this has to be the case if groups like A62, or CSI, AIA, and Producers Council can obtain the necessary support to develop standards. If support cannot be obtained then, closed systems will undoubtedly begin to take over in the near future. The impact of such change might well be left to your imagination. Manufacturers of building products will be faced with selling to building systems producers rather than individual distributors and architects, engineers or contractors. Mass buying practices will certainly change not only the distribution pattern but the cost structure.

Open construction systems are not by any means precluded from a healthy existence in the future. If we are to have open systems, the following recommendations are suggested.

First, we have interim communication standards that are adequate for our paper technology as we use it today. They should be adopted quickly with no more money, time, or energy spent on them. We must use them as the interim tools that they are and let's move on to more important things.

Second, we need significant sums of money to develop good standards for the future. Errors will be repeated millions of times. The Level V systems must be sound and well based. It will require significant sums of money to develop them. The new systems can no longer be developed by the common denominator acceptable to a committee, but will require special teams of unquestioned excellence applied over a period of time.

Third, the program deserves more than the back of the hand approach given it to date by both government and industry. It is time for government and industry in this particular area to reach an accommodation and work jointly together for the common good. Government will continue regardless of whether it is an open or closed construction system. The same statement cannot necessarily be made for industry.

We at Stanford Research Institute are going to be in the throes of developing an "Open-ended System for Specification Automation." We welcome the advice, assistance and comments of anyone that would like to contribute to the success of this first venture into the development of standard systems of design and construction softwear.

## BIOGRAPHIES OF THE SPEAKERS

GIFFORD H. ALBRIGHT has served as Head of the Department of Architectural Engineering at the Pennsylvania State University since it was established in 1962. He received his bachelor's degree from the Department of Architecture at Pennsylvania State University and a Master of Science in building engineering and construction from MIT.

Professor Albright is associated with research and instruction using the computer as a tool for architects, engineers, and building contractors, and has received National Science Foundation grants. He has prepared numerous articles and papers dealing with computer-aided planning and design in the building industry, including computer graphics and coordinated graphical input systems.

Professor Albright's professional affiliations include the American Society for Engineering Education, Association of Collegiate Schools of Architecture, American Society of Civil Engineering, American Society of Military Engineers, National Fire Protection Association, and a memher of the Building Research Advisory Board, Building Research Institute of the National Academy of Sciences, Washington, D.C.

A. ALLAN BATES is serving as Director, Office of Product Standards, U.S. Department of Commerce, advising the Assistant Secretary of Commerce for Science and Technology on matters of standards policy. Dr. Bates also continues as Chief of the Office of Engineering Standards Liaison in the Office of the Director, National Bureau of Standards. In this position he has charge of analyzing and coordinating engineering standards work of the Bureau with that of other Government agencies and with private national and international standards organizations. Dr. Bates is a former Chief of the Building Research Division, NBS.

Before this he was Vice President, in Charge of Research and Development, for the Portland Cement Association; manager of chemical, metallurgical, and ceramic research for Westinghouse Electric Corp.; Professor of Metallurgical Science at Escola Politecnica in Sao Paulo; President of the American Society for Testing and Materials; Vice Chairman of the Building Research Advisory Board of the National Academy of Sciences-National Research Council; and, a member of the Board of Directors of the Building Research Institute. Dr. Bates is Past-President of the American Concrete Institute and a member of the USA National Committee for the International Council for Building Research.

KLAUS BLACH, M.A.A., DAL, is Head, Building Techniques Department, Danish Building Research Institute. Mr. Blach has gained worldwide acknowledgement as a leading expert on modular coordination and industrialized building. In this capacity he has conducted more than 30 courses (during the last 5 years) in Denmark and abroad (usually 3-day courses on industrialization and modular coordination). In addition, he is known as a Lecturer at the Royal Academy of Fine Arts; a United Nations Building Research Expert (Indonesia 1958–61, Korea 1966–67 and 1968); a Member of the Danish Standardization Council, the Main Technical Council for Building in Denmark, the International Modular Group, many ISO Groups and, many CIB working groups. Somehow he also manages to act as the daily editor of the Danish Building Manual (Byggebogen) and as author or coauthor of quite a number of books, booklets, reports and so on, some of them in English.

WILLIAM K. BURTON is Manager of Metric Systems Development, Ford Motor Co. Previous to recently assuming this position he was Manager of Engineering Facilities and Services, General Services Division, Ford Motor Co.

Mr. Burton is a member of the Society of Automotive Engineers; Engineering Society of Detroit; Standards Engineers Society; USA Standards Institute Metric Advisory Committee and Chairman of its Task Force for Liaison with Company & Business Studies; and the Automobile Manufacturers Association Metric System Study Group.

Over the past several years, Mr. Burton has conducted worldwide studies of measuring systems and their effect upon standardization. He has written many articles relative to measuring systems, standardization, and facility planning.

MICHAEL D. CLARKE, ARIBA, Manager of the Contruction Group, British Standards Institution was responsible for coordinating the metric change in the British construction industry during the initial planning phases, including the important inclusion of modular coordination in building.

An architect in his early thirties, Mr. Clarke has firsthand experience of industrialized building systems, their design and application, and also of working in the metric system in the building field. His current responsibilities include the production of British Standards and Codes of Practice in the construction and building industries involving the wide practical application of modular coordination and metrication.

ARTHUR R. COGSWELL, a practicing architect, is a principal in the firm of Cogswell/Hausler Associates in Chapel Hill. He was project director for the U.S. Housing and Urban Development Low-Income Housing Demonstration which developed the IBIS computer-based cost analysis system for low-income housing.

His central professional interest is the application of computer technology to building design. This interest led him recently to participate with associates in the organization of the Advanced Planning Research Group, which was formed primarily to service clients in this area of professional interest. However, Mr. Cogswell continues his activity as a practicing architect in Chapel Hill with emphasis upon low-income housing.

JOHN A. DAWSON is in the service of the Canadian Government and is concerned with economic measures for increasing productivity and efficiency in the manufacture and use of building equipment accessories and materials in Canada. Currently serving in Ottawa, Ontario, he is a graduate Mechanical Engineer, College of Technology, Belfast, Ireland. In addition, Mr. Dawson is a graduate in psychology and economics, McMaster and Carlton Universities, Ontario.

He is experienced in mechanical, electrical, and civil engineering, as related to heavy machinery, textiles, chemicals, and building products manufacture and in the fields of atomic power generation and construction. Mr. Dawson is the author of several publications on the subjects of Modular Coordination and Industrialized Building.

CHARLES E. DIEHL, a Registered Professional Engineer, received a Bachelor of Architectural Engineering from Catholic University, a Bachelor of Civil Engineering from Rensselaer Polytechnic Institute, and a Master of Business Administration from the George Washington University. He is a member of the National Society of Professional Engineers, the Society of American Military Engineers, and Tau Beta Pi.

Mr. Diehl's primary areas of interest are in the solution of management problems and the development of communications systems related to the design, construction, and maintenance of buildings and other facilities. He has held positions as field and office engineer for a large general contractor; design and

construction manager for tracking stations on the Atlantic Missile Range (now Eastern Test Range); Director of Management Systems for the Navy's Bureau of Yards and Docks (now Naval Facilities Engineering Command); and, Vice President and Director of Management Planning for a large architectural and planning firm.

Mr. Diehl is now pursuing his primary areas of interest as a member of the senior staff in the Facilities and Housing Research Department of the Stanford Research Institute in Washington, D.C.

PETER FLOYD received his B.A. and M.A. from Massachusetts Institute of Technology. He is a registered architect in the Commonwealth of Massachusetts; the United Kingdom; and, is an associate, Royal Institute of British Architects. At present, Mr. Floyd is a Principal in the well-known firm of Geometrics, Inc., Architects and Engineers, Cambridge, Mass. Before becoming affiliated with Geometrics, Incorporated in 1956 he was Associate Profesor, Cornell University, College of Architecture; Visiting critic, Yale University, School of Art and Architecture; and, Instructor, Harvard University, Graduate School of Design. In addition, he has acted as a consultant to Institute of Applied Technology, National Bureau of Standards, U.S. Department of Commerce on building systems and application of new technological development to construction projects.

He was responsible for design of U.S. Pavilion at EXPO 67, and is a Member, U.S. Department of Commerce CTAB Panel on Housing Technology.

PAUL L. GARCIA was born and educated in Texas. His experience has been gathered in several architectural firms as well as Southwest Research Institute of San Antonio, where he served as Research Architect, Building Research Section. At Southwest he conducted a research project for the Texas Education Agency-Development on the principles for modular coordination for planning, design, material component sizing and assembly of construction elements in general and in particular to schools, as well as other projects on the Design Study and Market Potential of Plastic Products for Building Construction, function and conformance requirements for plastic products for use in residential, commercial-office, institutional-hospital, and educational-classroom building types. Also, structural components and shell construction, construction aids (forms, protective coatings, and fastening systems) were examined.

In 1958, he organized his architectural firm at San Antonio, Tex. A Corpus Christi office was established in 1967. Mr. Garcia is qualified by experience in architectural research; architectural design analysis; construction methods and construction materials; technology; modular planning, fallout shelter analysis; and, environmental engineering.

JACK E. GASTON is a graduate of the Missouri School of Mines and Metallurgy obtaining a BS degree in Metallurgy in 1934. His entire career has been spent in research activities—8 years with Eagle-Picher Industries and 27 years with the Armstrong Cork Co. He is currently Technical Consultant for Building Products Research in Armstrong's Research and Development Center. Past Technical Association activities have included several posts in ASTM work, Program Chairman and Board of Directors assignments in the Building Research Institute and current responsibilities as Chairman of the USASI A62 Committee.

HARVEY R. GEIGER recently joined the staff of the Battelle Memorial Institute after receiving a Master's degree in Architecture and a Master's degree in City Planning from Yale University in the spring of 1969. He has the distinction of being the first student at Yale enrolled simultaneously as a Master's candidate in Architecture and City Planning.

During the past 3 years he has traveled widely in the United States and Europe, studying building technologies and the organization of the building industry. Before joining Battelle as a construction analyst in the Construction Economics and Planning Division, he served as a consultant to them on several projects.

ROBERT HUGHES attended Liverpool College of Building. Professionally qualified as a Quantity Surveyor, he was recruited by a major Canadian construction company and immigrated to Canada in 1957. Before this he was Senior Quantity Surveyor, private practice, in England, concerned with schools, hospitals, and factory buildings. In Canada he has engaged in construction management in both Canada and Caribbean. Typical projects included: C.I.L. House in Montreal; McIntire Medical and Science Centre in Montreal; Trinidad Hilton Hotel in Trinidad; King George V Hospital, Bermuda; Budd Automotive Plan, Ontario; large shopping plaza in Nova Scotia; Habitat '67'; and, project management services, R.A.S. Systems School Building Project in Montreal. His interest in Systems Building goes back to the production of unit hutted camps for the Army in World War II and follows through postwar and prefabricated houses and schools culminating in the recent R.A.S. project and in further studies of housing.

JAMES R. HYDE, after receiving his B.S. Degree at Georgetown University, spent 15 years in the preengineered building industry in key management positions in: sales, marketing, and manufacturing, covering national and international distribution, both direct and through dealer organizations. During this period he was Vice President, Sales and Manufacturing for a wood home manufacturer, Vice President of Marketing and Sales for an aluminum and steel curtain wall home. He also developed a marketing program for metal building subsidiary in the capacity of Assistant to the President in Marketing, and also served as Assistant Director of a training and educational program under the auspices of The American Council on Education.

He founded J. R. Hyde & Associates, Inc. in 1965, has since served major firms desiring entry or expansion into the pre-engineered building industry.

JAMES A. PARKER was born and educated in Massachusetts. He served in the Army Air Force during World War II. He received a Bachelor of Architecture Degree from the Massachusetts Institute of Technology in 1951, and was employed by the firm of Harley, Ellington & Day, Inc., of Detroit, Mich., and by the Detroit Board of Education prior to entering Federal service with the General Services Administration in 1960. Registered as an Architect in Michigan in 1955, he is a member of the American Institute of Architects.

Mr. Parker is presently Assistant Chief, Specifications and Standards Branch, Public Buildings Service, GSA, where he is responsible for the research and development of specifications, standards, and criteria for a nationwide public building program. In addition to representing ANSI Committee A62, he also represents GSA on ANSI Committee A–117 on Facilities for the Physically Handicapped, ASTM Committee C–20 on Acoustical Materials, and BRAB–FCC Standing Committee on Architecture and Architectural Engineering.

NORMAN L. RUTGERS is Assistant to the President, Lennox Industries, Inc., Marshalltown, Iowa. His duties involve special assignments of a corporate nature, including large consumer account coverage and responsibility for giving sales assistance to the nine Lennox divisions in the United States and Canada for specific products.

A native of Holland, Mich., Mr. Rutgers received bachelor's degree from Illinois Institute of Technology. After discharge from the service he spent 10 years with Minneapolis-Honeywell, first in residential controls sales in western Michigan, then as account executive in Detroit and, finally, branch manager for the company in Des Moines, Iowa. He joined Lennox Industries, Inc. in 1956, became market manager of school sales and later Director of Educator for Lennox, until receiving his present assignment in 1968.

He has recently been involved in several systems projects such as the State of Florida school project (S.S.P.); the Pittsburgh Great High School Project; the University of California Dormitory Project; the Montreal and Toronto school projects; several low-income housing proposals; a Veterans' Administration Hospital project; a U.S. Post Office project; and, a government office construction project. He is

a Member of American Society of Heating, Refrigeration, and Air Conditioning Engineers, has served on the School Advisory Committee of the State of New York, and presently is a member of the Systems Subcommittee of the U.S. Department of Standards and Board of Governors, School Facilities Council.

L. R. SHAFFER is a native of western Pennsylvania. He received his B.S. degree in Civil Engineering from the Carnegie-Mellon University in 1950. After 2 years as Assistant Master Mechanic for the Sharon works of the National Castings Co. and an additional 2 years as the Assistant to the Director of Engineering of the Sharon Steel Corp., he joined the staff of the University of Illinois in Urbana where he earned the M.S. and Ph. D. degrees in 1957 and 1961, respectively.

In 1961 he was appointed Head of the Construction Engineering group in the Department of Civil Engineering and in 1963 was Cochairman of the Civil Engineering Systems Laboratory. On July 1, 1969, he assumed his present position—Deputy Director of the Construction Engineering Research Laboratory of the U.S. Army in Champaign. Ill.

Dr. Shaffer is the author of some 50 articles, papers, and texts in the application of systems analysis, operations research and computer-based approaches to the decisionmaking functions undertaken by all levels, and forms, of management in the construction firm.

RUSSELL W. SMITH, JR., is Secretary and Vice Chairman of the American National Standards Institute's National Standards Committee A62, Precoordination of Building Components and Systems, sponsored by the National Bureau of Standards, Department of Commerce. In addition, he is project manager of NBS technical and administrative support for A62.

Employed by the NBS in the summer of 1964, he has served as a special assistant to the Director of the NBS Institute for Applied Technology; as assistant to the Chief, Office of Engineering Standards Liaison, Office of the Director, NBS; and, in the NBS Building Research Division.

In the 10 years before joining the NBS, Mr. Smith gained considerable experience in construction industry problems and procedures serving as technical director of Producers' Council and later as technical director of The Plumbing Fixture Manufacturers Association.

Beginning his academic training as an architectural engineering major, Mr. Smith's education was interrupted by World War II. Following the War, he went into business as a speculative homebuilder, operating his own organization at Roanoke, Va., for some 6 years. He then took a position as technical editor of Transport Topics, a publication of the American Trucking Association, Washington, D.C. so that he could complete his academic training in night classes at American University, and received a B.A. in Economics.

In 1953 he joined the engineering staff of Convair Aircraft, working on the Atlas missile program. In 1955, he returned to Washington, D.C., to become the technical director of Producers' Council.

DR. MYRON TRIBUS, Assistant Secretary of Commerce for Science and Technology, attended the University of California at Berkeley where he received his B.S. in Chemistry in 1942. He received his Ph. D. in Engineering from the University of California at Los Angeles where from 1946 to 1960 he taught engineering, rising from instructor to professor.

In 1950 he served as a consultant in heat transfer at General Electric Co., and has worked as a consulting engineer since that time. From 1951–54 he was director, Aircraft Icing Research at the University of Michigan. He became Dean of Thayer School of Engineering at Dartmouth College in 1961.

Dr. Tribus has been a member of the Commerce Technical Advisory Board, served as a consultant to the Federal Office of Saline Water for the Department of the Interior, and served as an advisor to NATO. He has also been a director of the Carpenter Technology Corp., a major producer of specialty steels.

He is the author of a text book, *Thermostatics and Thermodynamics*, 1961, and a new book, *Rational Descriptions, Decisions and Designs*, is now in press. He is a member of the American Society of Mechanical Engineers; the Institute of Electrical and Electronics Engineers; and the American Society for Engineering Education.

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